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THE ANNEALING OF GLASS.*

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INTRODUCTION.

Definition of Annealing.—It is well known that quickly cooled glass is in an unstable condition due to stresses acquired in cooling. Such glass is said to be "strained," and if the strain is excessive, the glass may crack or even fly to pieces when handled, or when heated or cooled. If the strained glass be heated to a sufficiently high temperature and then slowly cooled, it may lose a considerable part of its internal stress. This operation of removing or diminishing the strains in glass is called annealing. It should be noted that this is not the only use of the word annealing, which is often applied to other kinds of transformations. A metal such as silver when drawn, hammered or otherwise deformed, undergoes a physical change and acquires increased hardness which it may lose when heated. It is then said to be annealed. "Annealing" is also used to characterize the chemical and physical changes taking place in the complex mixture, steel, when it is heated to certain temperatures. In the present discussion, however, we use the term annealing only in connection with the relief of internal stress, a process which has no necessary connection with the other above-mentioned physical processes.

Reason for Annealing of Glass.—The removal or prevention

* Communicated by Dr. Arthur L. Day, Director of Laboratory.

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of excessive strain is one of the many difficult problems encountered by the glassmaker. When glass is poorly annealed large losses by breakage may occur during the customary cooling process, and even if the glass has been completely cooled without fracturing, it may show an annoying liability to breakage when handled at some subsequent time. A proper and efficient method of annealing is therefore a necessary part of the manufacture of glass of any kind, and is of very highest importance in dealing with optical glass.

While commercial glassware such as plate glass, window glass, bottles, chemical glass, cut-glass and so forth must be free from excessive strain, optical glass requires a much more complete and perfect annealing process. Quite apart from the loss due to breakage, strain in optical glass is to be avoided since it may cause the surface of lenses and prisms made from the glass to warp or distort,[1] thus spoiling the optical definition.

Lack of Data on Annealing.—Our attention was first directed toward this subject in 1917 when the Geophysical Laboratory was called upon to develop methods for the various operations involved in the manufacture of optical glass. In the early part of that year little was known in this country about the making of optical glass. The compositions of most of the important glasses were available,[2] some progress had been made at three or four places in evolving the technic of melting, but the sum total of known facts was very small, and concerning the annealing of optical glass or any other kind of glass the lack of definite information was especially striking. Schott,[3] in 1891, had determined for several glasses the lowest temperature at which an undoubted diminution of stress took place within twenty-four hours, and more recently Zschimmer and Schulz[4] had investigated the amount of stress produced in glass by cooling it suddenly from various temperatures, but altogether the published records up to the year 1917 contain practically nothing on which to base a rational schedule for the annealing of glass. Therefore when confronted with the problem of annealing the vast quantities of

[1] See H. Hovestadt: "Jena Glass," p. 15.

[2] See, for example, Zschimmer's tables in Doelter's "Handbuch der Mineralogie."

[3] O. Schott: *Z. Instrumentenkunde* 11, 330-337 (1891).

[4] E. Zschimmer and H. Schulz: *Ann. Phys.* (4) 42, 345-396 (1913).

optical glass required for military and naval instruments, the first step necessarily involved a systematic study of the annealing process, in the factory and in the laboratory, and a quantitative determination of various factors such as the temperature for best annealing, the allowable cooling rates, and the relation between strain and temperature gradient. Experimental work on annealing was done by several members of the scientific staff of the Geophysical Laboratory. G. W. Morey and F. E. Wright carried out investigations at the plant of the Bausch and Lomb Optical Company; W. P. White at the Geophysical Laboratory; H. S. Roberts, L. H. Adams and E. D. Williamson at the Charleroi plant of the Pittsburgh Plate Glass Company; and the last two also at the Geophysical Laboratory. The application of the results to the actual annealing of optical glass on a large scale in the factories [5] has met with entire success.

Previous publications of this Laboratory have already presented details concerning certain subsidiary problems [6] bearing upon this subject, and it now remains to describe the annealing process and to correlate the results of the earlier investigations.

The Generation and Release of Strain.—Before describing the method used by the authors in determining the proper procedure for annealing glass, it is desirable to consider in a general way the generation and release of internal stress.[7] Glass is an amorphous material which at ordinary temperature is as hard and rigid as a typical solid, but when heated it gradually softens as

[5] During the war over 600,000 pounds of optical glass was delivered to the U. S. military establishment, and of this amount over 95 per cent. was manufactured under the direct supervision of various members of the scientific staff of the Geophysical Laboratory.

[6] See, for example, E. D. Williamson and L. H. Adams: Temperature Distribution in Solids During Heating and Cooling, *Phys. Rev.*, 14, 99–114 (1919); L. H. Adams: Tables and Curves for Use in Measuring Temperature with Thermocouples, *Trans. Am. Inst. Min. Met. Eng.*, 2111–2124 (1919); E. D. Williamson and H. S. Roberts: Thermocouple Installation in Annealing Kilns for Optical Glass, *Ibid.*, 1445–1453; E. D. Williamson: Strains Due to Temperature Gradients, with Special Reference to Optical Glass, *J. Wash. Acad. Sci.*, 9, 209–217 (1919); L. H. Adams and E. D. Williamson: The Relation Between Birefringence and Stress in Various Types of Glass, *Ibid.*, 9, 609–623 (1919).

[7] The word stress commonly denotes a force per unit area, and strain a relative deformation. Since stress usually accompanies strain, the two words are often used interchangeably, but it is important to bear in mind that they are not synonymous.

the temperature is raised, until it becomes a viscous and finally a thin liquid. During cooling the reverse process takes place, the glass changing without discontinuity from a thin liquid to a rigid "solid." This range of temperature through which occurs a continuous "solidification" of a single phase, is peculiar to undercooled liquids and is never observed with crystalline solids.

Suppose now that a flat plate or slab of glass, originally free from stress and of a uniform and comparatively low temperature, is heated at both faces—that is, at the two surfaces normal to the shortest dimension of the piece. The outside layers being hotter, tend to expand more than the inner, but this tendency is to a certain extent resisted by the inner layers; that is, the surfaces of the slab are not free to expand the normal amount and will therefore be under longitudinal compression—compression in all directions parallel to the faces of the slab. At the same time the innermost layer will be stretched by the outer layers and will be under tension.[8] Furthermore, the longitudinal stress changes continuously from a compression at the surface to a tension in the middle, and therefore at a certain distance below the surface there will be a layer with no stress, *i.e.*, a neutral zone. If now the temperature in the slab be allowed to become uniform throughout, thus regaining its original condition, the thermal gradient and hence the stresses will disappear. On the other hand, if the glass be cooled, there will be observed forces similar to those arising from heating, but opposite in sign; that is, tension on the outside and compression in the middle. In general, then, a temperature gradient established by heating will produce in the outer layers a longitudinal compression, and a gradient established by cooling will cause a longitudinal tension.[9] Similarly, if for any reason a temperature gradient exist in a slab free from stress,[10] the removal of the temperature gradient (as, for example, by maintaining the surface at a constant temperature) will cause

[8] The block is assumed to be large enough so that the end effects may be neglected.

[9] In solids of other shapes the distribution of stress will be more complicated than in the slab. In a sphere, for example, which is being heated, there will be a radial tension all the way from centre to surface, a tangential compression in the outer layers, and a tangential tension in the central portion.

[10] *E.g.*, see below (December number), for the case for glass cooled at a constant rate from a high temperature.

stresses equal and opposite in sign to those which would be produced by the establishment of the same temperature gradient.

Temporary and Permanent Strain.—So much for the behavior of glass at temperatures not too high; that is, at temperatures such that the glass does not flow appreciably and thus acts like an elastic solid. At higher temperatures, however, the situation may be quite different. The glass may flow, and by internal displacements the stresses may gradually relieve themselves, the rate of release being dependent on the viscosity, which in turn decreases steadily as the temperature is raised. Consequently the stresses engendered in a block of glass by heating or cooling as described above may not be permanent; indeed, for temperatures at which the glass becomes a thin liquid the stresses may be so evanescent as to escape detection.

The stresses already discussed may be called *temporary*, since they continue only so long as the causative temperature gradient is maintained and tend to disappear even at low temperatures by removal of the temperature gradient. Let us now inquire how a block of glass may receive *permanent* stresses; that is, stresses which persist in glass even though it may be without thermal gradient. Consider a slab of ordinary plate glass at, say, 650° (a temperature at which stresses in this kind of glass disappear almost instantaneously), and suppose that its surface be allowed to cool at a uniform rate. As shown in a previous publication,[11] within a certain time after the commencement of uniform heating or cooling the temperature distribution will be practically parabolic and will remain constant so long as the time rate of temperature change remains constant. We will suppose then that the temperature gradient in the block of glass has reached a steady state while the glass is yet soft and thus unable to retain the temporary strains caused by the introduction of this gradient. The glass, therefore, will not be under stress while the temperature gradient is being established, nor, so long as it is being cooled at a uniform rate, will there be any stress developed, because the temperature differences in the transverse direction remain constant. But when the surface of the glass has arrived at the temperature of the surroundings (say, room temperature), we may suppose that it is cooled no further and that the temperature finally becomes uniform throughout the slab. The

[11] E. D. Williamson and L. H. Adams: *Phys. Rev.*, 14, 108 (1919).

removal of this temperature-gradient, as explained above, will cause stresses of the same kind as those produced by heating, and consisting therefore of longitudinal compression on the outside and tension on the inside. Strain caused by this system of stresses we shall call *ordinary* strain, since it is the usual kind of permanent strain, and strain introduced when a solid is beginning to cool we shall call *reverse* strain.

It thus appears that a block of glass cooled from a temperature at which it is soft to some other temperature at which it is hard, acquires at the lower temperature *ordinary, permanent* strain. Figure 1 indicates graphically how a slab of glass may receive strain by cooling from a high temperature. The dotted lines indicate strain and the full lines temperature distribution

FIG. 1.

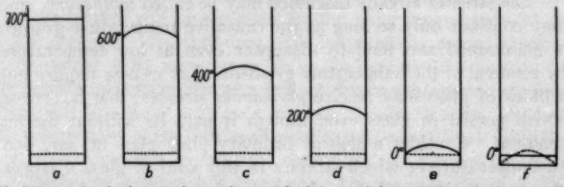


Diagram showing in several stages how a slab of glass cooled at a *uniform* rate from a sufficiently high temperature receives internal strain only when the cooling is stopped. The abscissæ represent distances in a direction normal to the surface, and the ordinates represent temperature (full lines) or strain (dotted lines).

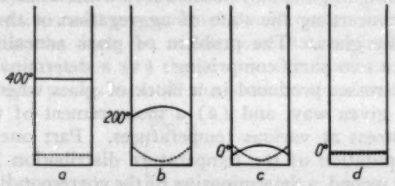
in a direction normal to the faces of the slab, which in the figure is assumed to be 2 cm. thick and to be cooled at a rate of 10° C. per minute.

On the other hand, as shown in Fig. 2, glass at a temperature below that at which appreciable softening occurs, and initially without thermal gradient, will not acquire permanent strain when cooled to room temperature, the reverse strain introduced when the glass begins to cool being exactly balanced by the ordinary strain set up when the temperature gradient is ironed out at the lower temperature.

It is evident, therefore, that in dealing with the internal strains caused by the uniform cooling of glass we may consider two limiting cases: (1) cooling from a relatively high temperature with the production of permanent strain, and (2) cooling from a relatively low temperature, in which case no permanent strain is introduced.

Glass cooled from some intermediate temperature will acquire internal strain, the amount of which will lie between the amounts received in the two above-mentioned cases. Referring to Fig. 3, let the slab of glass initially at 500° throughout and free from stress be cooled as before at a rate of 10° C. per minute. Then,

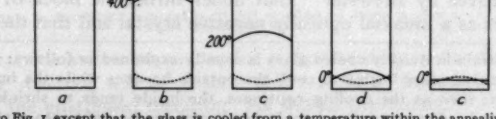
FIG. 2.



Similar to Fig. 1, except that the glass is cooled from a temperature below the annealing range, in which case no permanent strain is introduced.

just as in the previous case, a parabolic temperature gradient is soon established in the block, thereby causing a certain amount of reverse strain, but while the gradient is being established, or after the gradient has been established, part of this reverse strain will disappear by viscous yielding of the glass, and there-

FIG. 3.



Similar to Fig. 1, except that the glass is cooled from a temperature within the annealing range. In this case strain is introduced, but less in amount than that shown in Fig. 1.

fore when the gradient is finally ironed out at room temperature the reverse strain will not be sufficient to neutralize the ordinary strain produced at the lower temperature. The residue is the strain finally observed.

Nature of the Problem.—Although the foregoing discussion has been limited to the special case of cooling at a uniform rate, a little consideration will show that the explanation given may

be extended to other kinds of cooling and that in general *the strain remaining in a block of glass is equal and opposite in sign to the reverse strain lost by viscous yielding in the early stages of the cooling process.*[12] In its larger aspects, then, the formation and removal of strain in optical and other glasses may be treated as a purely mechanical process, and most of the questions involved in the annealing of glass may be answered without having recourse to matters concerning the state of aggregation or the molecular nature of the glass. The problem of glass annealing may be resolved into two parts comprising: (1) a determination of the temporary stresses produced in a block of glass when heated or cooled in a given way, and (2) a measurement of the rate of release of stress at various temperatures. Part one, involving first, a computation of the temperature distribution in glass on cooling, and second, a determination of the corresponding stresses, has been treated in previous publications from this Laboratory.[13] For part two, we have now obtained the requisite data, and in what follows we present the results of our measurements on the rate of release of stress, together with a description of the method and a discussion of the bearing of these results on the annealing of glass.

EXPERIMENTAL DETERMINATION OF RELEASE OF STRAIN.

Detection of Strain.—When a block of glass is subjected to a thrust it becomes doubly refracting, and when viewed in polarized light between crossed nicols it shows interference colors. It was first proved by Brewster[14] that under thrust the block of glass behaves as a uniaxial optically negative crystal and that the bire-

[12] Strain in quickly cooled glass is usually explained as follows: When the softened glass begins to cool, the outside hardens while the inside is yet soft; then as the cooling continues, the inside tends to shrink away from the hardened crust and the outer layers are brought into a state of thrust and the inner layers into a state of tension (compare Hovestadt, *op. cit.*, pp. 66, 67). This explanation is not only incomplete but it is misleading. It takes no account of the fact that a lump of soft glass under certain conditions may be rapidly cooled to a completely hardened state without any strain being introduced before, during, or after the hardening of the outer crust. It takes no account of the fact that ordinarily a large part of the strain found in unannealed glass has arisen at comparatively low temperatures, far below the hardening range, and it ignores the existence of temporary stresses and of the dependence of stress upon direction.

[13] *Phys. Rev.*, 14, 99–114 (1919). *J. Wash. Acad.*, 9, 209–217 (1919).

[14] Brewster: *Phil. Trans.*, 1814, 1815, 1816.

fringence is proportional to the intensity of the stress. The method commonly used for the detection and measurement of strain in glass utilizes this phenomenon. In actual practice light polarized by reflection or by means of a nicol prism is passed through the glass and then through a second nicol prism. As viewed between crossed nicols, unstressed glass remains dark, but stressed glass shows interference colors from which may be inferred the directions and amounts of the stresses. In order to see how this may be done, let us suppose that, as in Fig. 4, a block of glass is subjected to a thrust F in the direction OY and that a ray of light passes through the block in the direction OX.

FIG. 4.

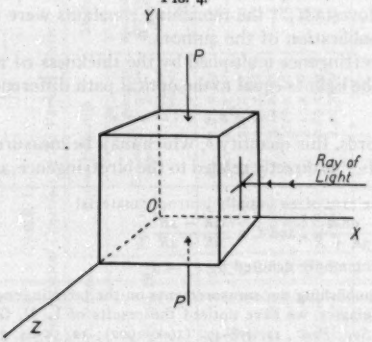


Diagram to accompany explanation in text of effect of strain in glass on a beam of polarized light.

The refractive indices n_y and n_z for light vibrating in the directions OY and OZ will in general differ from n, the refractive index in the unstressed medium. As shown previously,[15]

$$\frac{n_y - n}{n_y} = \frac{F}{E}\left(-2\sigma\frac{p}{v} + \frac{q}{v}\right) \qquad (1)$$

and

$$\frac{n_z - n}{n_z} = \frac{F}{E}\left[(1-\sigma)\frac{p}{v} - \sigma\frac{q}{v}\right] \qquad (2)$$

[15] *J. Wash. Acad. Sci.*, 9, 618 (1919).

It may also be noted that for a simple thrust or tension the stress F is related to the strain S by the relation

$$S = F/E$$

in which $\frac{p}{v}$ and $\frac{q}{v}$ are optical constants, E is Young's modulus of elasticity, and σ is Poisson's ratio.[16] Moreover, the birefringence,[17] $n_y - n_z$, is equal to a constant B times the thrust F, thus

$$n_y - n' = BF \tag{3}$$

in which

$$B = \frac{n}{2R}\left(\frac{q}{v} - \frac{p}{v}\right)$$

R being the rigidity.

In Table I the values of B for the glasses which we have investigated [18] are tabulated, along with other chemical and physical constants. The values of α, the coefficient of expansion, and κ, the thermal diffusivity, were calculated for the most part from data given by Hovestadt; [19] the remaining constants were copied from a former publication of the authors.[20]

The birefringence multiplied by the thickness of material traversed by the light is equal to the optical path difference δ; that is,

$$l(n_y - n_z) = l\Delta n = \delta \tag{4}$$

in other words, this quantity δ, which may be measured by standard methods,[21] is directly related to the birefringence, and hence, by

[16] For the case of an initially isotropic material

$$E = \frac{9KR}{3K + R}, \text{ and } \sigma = \frac{3K - 2R}{6K + 2R}.$$

[17] Also commonly denoted by $n_\varepsilon - n_\omega$.

[18] Since publishing our measurements on the birefringence-stress ratio for various glasses, we have noticed the results of L. N. G. Filon, *Cambridge Phil. Soc., Proc.*, **11**, 478–492 (1900–1902); **12**, 55–64, 313–337 (1902–1904). Measurements were made at different wave-lengths. In order to compare his results with ours the values of B for wave-length 550$\mu\mu$ are given below:

Glass	Per Cent PbO	Base
Jena, O–152	16	2.72×10^{-7}
Jena, O–154	31	2.88×10^{-7}
Jena, O–103	47	2.83×10^{-7}
Jena, O–192	56	2.22×10^{-7}
Jena, O–41	63	1.74×10^{-7}
Jena, S–57	79	-1.05×10^{-7}
Plate glass	..	2.58×10^{-7}

[19] *Op. cit.*, pp. 147, 196, 210, 215.

[20] *J. Wash. Acad. Sci.*, **9**, 612, 613 (1919).

[21] See, for example, F. E. Wright: "The Methods of Petrographic Microscopic Research." Carnegie Institution of Washington, *Publ.* **158**, Chap. iii, 1911, or any text-book on optics.

TABLE I.

Chemical and Physical Constants of the Various Glasses.

Kind of glass	Chemical composition (approx.) wt. per cent.									Optical Properties			Mechanical Properties		Thermal Properties	
	PbO	CaO	BaO	ZnO	Na_2O	K_2O	Al_2O_3	B_2O_3	SiO_2	Refr. ind. n_D	Constringence ν	Birefringence due to 1 kg/cm² tension B	Modulus of compressibility Kg/cm² K	Modulus of rigidity Kg/cm² R	Coeff. of linear exp. a	Thermal diffusivity cm²/sec. κ
Borosilicate crown	—	—	4	—	9	8	—	12	67	1.516	62	2.85×10^{-7}	0.43×10^6	0.29×10^6	7.5×10^{-6}	0.0045
Ordinary crown	—	12	—	—	14	1	—	—	73	1.523	59	2.57×10^{-7}	$.46 \times 10^6$	$.28 \times 10^6$	8.9×10^{-6}	.0047
Light barium crown	—	—	29	11	3	5	1	4	47	1.574	57	2.81×10^{-7}	$.52 \times 10^6$	$.30 \times 10^6$	7.4×10^{-6}	.0039
Heavy barium crown	—	—	43	8	—	—	3	6	40	1.608	57	2.15×10^{-7}	$.53 \times 10^6$	$.29 \times 10^6$	6.4×10^{-6}	.0040
Barium flint	24	—	15	8	3	4	—	—	46	1.606	44	3.10×10^{-7}	$.42 \times 19^6$	$.26 \times 10^6$	7.7×10^{-6}	.0038
Light flint	35	—	—	—	6	5	—	—	54	1.573	42	3.20×10^{-7}	$.35 \times 10^6$	$.24 \times 10^6$	8.4×10^{-6}	.0040
Medium flint	48	—	—	—	3	4	—	—	45	1.616	37	3.13×10^{-7}	$.34 \times 10^6$	$.22 \times 10^6$	8.1×10^{-6}	.0038
Heavy flint	52	—	—	—	3	3	—	—	42	1.655	33	2.67×10^{-7}	$.34 \times 10^6$	$.22 \times 10^6$	8.2×10^{-6}	.0036
Extra heavy flint	69	—	—	—	—	3	—	—	28	1.756	27	1.22×10^{-7}	$.32 \times 10^6$	$.20 \times 10^6$	8.5×10^{-6}	.0033

equation (3), to the stress in the glass. In the actual measurement of strain in glass the sample is placed between crossed nicols and, for maximum brightness of interference colors, is so placed that one of the principal directions of the piece is at an angle of 45° to the vibration direction of the polarized light. In measuring the optical path difference, the interference color observed may be compared with a Newton color scale [22] and the path difference thus estimated, or the path difference may be read directly on a graduated quartz wedge (of the type used in the petrographic microscope) placed between analyzer and polarizer. We have made use of the second method, except for some preliminary measurements, but the first is the more useful for the routine testing of glass. One division on the wedge was equivalent to 10$\mu\mu$ and readings could easily be made to one-half division or 5$\mu\mu$.

The sign of the path-difference may also be determined, and, since for most glasses $n_\gamma - n_\alpha$ is negative in the case of a thrust, it is evident that having determined for any part of a strained block of glass the direction of α, the lesser index, and of γ, the greater index, we know that in the given part of the block there is either a tension parallel to γ or a thrust parallel to α, or both tension and thrust in the stated directions. A sensitive-tint plate on which the α and γ directions are marked may be used for this purpose. For a series of glasses of increasing lead content $n_y - n_z$ diminishes and finally changes sign at about 74 per cent. PbO. For a glass of this composition the ordinary method for the measurement of strain would fail; stressed and unstressed glass would present the same appearance when viewed in polarized light. But fortunately glass containing as much as 74 per cent. PbO is very unusual and is rarely encountered by the maker or user of glass.

Description of Apparatus.—Figure 5 is a diagrammatic representation of the apparatus used for measuring the rate of release of stress at various temperatures. In the electric muffle furnace F was placed a slab of glass B, which was placed with its shortest dimension vertical, and was supported at three points. One of the three supports was adjustable from the outside so that the

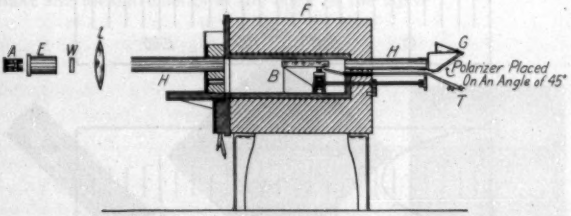
[22] Such charts may be found in J. P. Iddings' "Rock Minerals" (1911), and H. M. Winchell's "Optical Mineralogy" (1909).

A sensitive-tint plate, consisting of a plate of selenite (or other suitable material) having a path difference of about 570$\mu\mu$ is a common and important adjunct, especially for the estimation of a small amount of strain.

slab could be leveled and brought into line with the two circular openings, one in either end of the furnace. In these openings were fitted alundum tubes H, H (respectively 1.5 and 2.5 cm. in diameter), the object of which was to reduce convection currents between the cold air outside the furnace and the hot air inside. One side of the furnace chamber was closed by a door of refractory material.

Light from a lamp was diffused by the ground-glass screen G and polarized by reflection at a glass plate.[23] From the polarizer the light passed into the furnace, through the glass B and out through the tube H. The remainder of the optical system

FIG. 5.



Apparatus used for measurements of rate of release of stress in various glasses at various constant temperatures. F is an electric muffle furnace in which is supported the glass slab B. Light from a lamp is diffused by the ground glass screen G, is then polarized by reflection from a glass plate and passes successively through the slab B, the lens L, the wedge W (seen end on in the figure), the eyepiece E and the analyzing nicol A. Temperature is measured by the thermocouple T in conjunction with a potentiometer.

consisted of a lens L, a quartz wedge W placed horizontally, an eyepiece E which was focussed on W, and finally the analyzer, a cap nicol A. The wedge W was so graduated that one division corresponded to 10$\mu\mu$ optical path difference.[24] The analyzer and polarizer were crossed and the angle between the horizontal and the plane of polarization was 45°.

The appearance of the field of view as seen by the eye placed at A, is suggested by Fig. 6. At a is shown the field of view when the glass is unstrained, the vertical black line of zero path difference is straight and coincident with the zero of the scale.

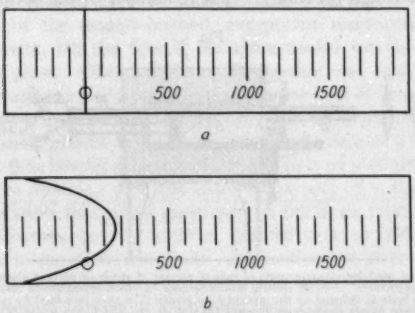
[23] For maximum polarization the angle of incidence is $\tan^{-1} n$. Taking n as 1.51, the angle is therefore 66.5°. Either black glass or ordinary glass blackened on the back may be used.

[24] A $\mu\mu$ is a millimicron or 10^{-7} cm.

The presence of internal strain is indicated by a curvature of the black line the position of which, with reference to the scale, shows the transverse distribution of strain. Thus in Fig. 6*b* the path difference through the middle of the slab is 170$\mu\mu$, at the surface is much greater but of opposite sign, while at a little more than half the distance from centre to surface it is zero.[25]

Temperature was measured with the usual equipment consisting of a platinum-platinrhodium thermocouple T, and a potentiometer (not shown in the figure) reading to 1 microvolt. The

FIG. 6.



This diagram suggests the appearance of the graduated wedge as seen through the eyepiece and analyzer (see Fig. 5). When the glass is unstrained (as at *a*) the black line is straight and coincident with the zero of the scale; but the presence of strain causes the line to become curved (as in Fig. 6*b*), and its position shows the distribution of strain throughout the block of glass. In the wedge actually used the divisions as shown in this figure were further subdivided so that 1 division equals 10$\mu\mu$ path difference.

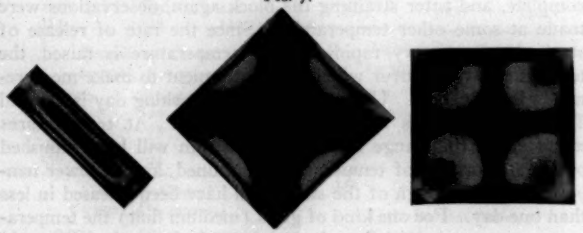
thermocouple junction was about 5 mm. below the lower surface of the glass. The temperature corresponding to 1 microvolt is about 0.1°, an unnecessarily high degree of precision for this work, but the greater sensitivity increases the ease of manipulation in maintaining a constant temperature by hand regulation. Time intervals were measured with an ordinary watch.

Method of Experiment.—In determining the rate of release of strain at constant temperature any one position in the slab may be chosen and successive observations of path difference at

[25] The curve of strain caused by heating or cooling at a constant rate is a parabola crossing the zero line at a distance from the centre equal to 0.578 of the semi-thickness. Cf. *J. Wash. Acad. Sci.*, 9, 216 (1919), and equation (54) below.

that position may be made. For the sake of convenience the middle was selected and only the position of the apex of the curve (Fig. 6*b*) was read. The complex end-effects at either side of a strained block of glass (as shown in Fig. 7*a*, *b*, and *c*) are far outside the field of view, and do not lead to any difficulties. It may be noted in this connection that for quantitative measurements a cylinder is not so convenient as a slab. If an unannealed glass cylinder be viewed along its axis, the path difference is zero at the centre and reaches its maximum value at the surface. Therefore, with a cylinder viewed lengthwise, the readings must be taken at some portion of the curve other than the apex; while with a slab one can take advantage of the convenience of being able to make the measurements at the apex of the curve.

FIG. 7.



a *b* *c*

Three photographs showing the appearance of a slab of strained glass when viewed in polarized light between crossed nicols. *a* shows the glass viewed through the ends; and *b* and *c* when viewed in the transverse direction. In each case the planes of polarization are parallel to the margins of the page.

The specimens of glass used were about 2 cm. in thickness and 8 cm. in length and breadth. Two opposite edges were polished and approximately plane parallel. Since the presence of striæ causes a distortion of the interference image, the best pieces were selected from a large quantity of glass.

The slab of glass having been placed in position was leveled and brought into line with the circular opening of the furnace. The thermocouple junction was then adjusted and the door closed. The first stage of the experiment consisted in getting strain into the glass. This was accomplished by raising the temperature about 50° above the temperature at which strain disappears almost instantaneously (see below) and then dropping the temperature rapidly by cutting off the current and opening the

door. When the temperature had fallen about 300° the current was turned on and the furnace brought up to the temperature at which the observations were to be made.

After this temperature had been reached, at least 20 minutes was allowed for the glass to attain a constant temperature throughout. The rate of release of stress at constant temperature was then determined by successive observations of path difference. The interval of time between readings depended on the rapidity with which the stress was released, so that at the higher temperature readings were taken a few minutes apart, while at lower temperatures several hours might elapse between two successive observations.

As a rule when the path difference had fallen to about 50$\mu\mu$ (5 or 6$\mu\mu$ per cm.) the series of measurements was considered complete, and after straining the block again, observations were made at some other temperature. Since the rate of release of strain increases very rapidly as the temperature is raised, the temperature-range over which it is convenient to make measurements is very short. Unless more than a working day is allowed for one series, this range is less than 50°. At temperatures much above this range nearly all the strain will have vanished before uniformity of temperature is attained, and at lower temperatures not enough of the strain will have been released in less than one day. For one kind of glass (medium flint) the temperature range was extended at the lower end by observing the strain remaining in the block of glass after immersion for several weeks in the vapor from boiling benzophenone (b.p. 306°). During this time the glass was taken out at intervals of a week or more, and after a measurement of the strain the glass was replaced in the benzophenone bath.

Experimental Results.—In Table II are collected the results of the several series of measurements obtained for each of the eight types of glass as defined by the properties already given in Table I. With each set of observations is shown the temperature, θ, the elapsed times, t, in minutes, and the corresponding values of δ, the optical path difference in $\mu\mu$. Each value for δ is the mean of two or more separate readings, usually by two independent observers. The method of obtaining the calculated values of δ (in the third column) and the significance of the factor A′ appearing at the top of each section of the table, will be discussed further on in the paper.

TABLE II.

Experimental Results. Measurements of Release of Stress at Constant Temperature.

Time	Path diff., δ	δ, calc. by equation 7b.
Borosilicate Crown $\theta = 480°$, $A' = .0000072$		
0 min.	284μμ	280μμ
69	240	246
157	209	213
214	200	196
Borosilicate Crown $\theta = 500°$, $A' = .000022$		
0 min.	462μμ	455μμ
31	338	347
76	252	258
149	170	182
209	153	147
314	118	110
Borosilicate Crown $\theta = 530°$, $A' = .00021$		
0 min.	236μμ	243μμ
22	122	115
44	73	75
98	33	41
156	24	27
Ordinary Crown* $\theta = 450°$, $A' = .0000034$		
0 min.	510μμ	500μμ
60	440	454
120	410	415
240	370	355
420	310	292
720	220	225
1080	160	176
1725	120	127
Ordinary Crown* $\theta = 470°$, $A' = .000024$		
0 min.	315μμ	312μμ
60	210	215
120	175	164
240	110	111
420	80	75
Ordinary Crown* $\theta = 490°$, $A' = .000049$		
0 min.	230μμ	230μμ
60	130	137
120	100	98
180	85	76
Ordinary Crown* $\theta = 500°$, $A' = .000105$		
0 min.	120μμ	123μμ
60	75	69
120	50	48
240	20	30
Ordinary Crown $\theta = 515°$, $A' = .00040$		
0 min.	208μμ	195μμ
5	133	140
10	113	109
20	88	76
50	(25)	(40)
Light Barium Crown $\theta = 500°$, $A' = .0000113$		
0 min.	732μμ	719μμ
12	646	656
33	547	567
64	436	473
143	325	333
230	256	251
342	215	190
Light Barium Crown $\theta = 516°$, $A' = .000028$		
0 min.	396μμ	400μμ
31	288	297
49	272	258
94	202	195
141	157	155
177	125	134
Light Barium Crown $\theta = 540°$, $A' = .00020$		
0 min.	162μμ	(162)μμ
29	83	(83)
Heavy Barium Crown $\theta = 540°$, $A' = .0000062$		
0 min.	668μμ	658μμ
25	586	594
62	511	522
88	464	482
129	416	429
175	379	382
284	309	304

TABLE II.—*Continued.*

Experimental Results. Measurements of Release of Stress at Constant Temperature.

Time	Path. diff., δ	δ calc. by equation 7b.
Heavy Barium Crown $\theta=565°$, $A'=.000034$		
0 min.	470μμ	483μμ
18	364	373
52	268	260
78	216	212
123	160	160
151	134	139
213	104	107
Heavy Barium Crown $\theta=590°$, $A'=.00047$		
0 min.	149μμ	152μμ
18	72	67
40	36	39
66	26	27
91	18	20
Barium Flint $\theta=450°$, $A'=.000022$		
0 min.	492μμ	493μμ
25	386	387
60	300	299
103	229	233
193	158	159
294	116	118
360	100	100
Barium Flint $\theta=470°$, $A'=.00013$		
0 min.	312μμ	324μμ
55	108	98
91	59	67
134	39	49
Barium Flint $\theta=490°$, $A'=.00031$		
0 min.	155μμ	156μμ
11	107	102
22	70	76
33	56	60
58	45	41
Light Flint $\theta=385°$, $A'=.000080$		
0 min.	415μμ	400μμ
11	280	296
22	223	235
34	188	192
Light Flint; $\theta=385°$, $A'=.000080$—*con.*		
48	155	158
72	118	121
100	100	95
140	80	73
Light Flint $\theta=400°$, $A'=.00017$		
0 min.	280μμ	289μμ
10	195	194
26	135	127
44	97	91
60	72	73
90	47	53
139	27	37
Light Flint $\theta=415°$, $A'=.00046$		
0 min.	293μμ	299μμ
5	185	177
10	130	126
20	80	80
28	58	62
40	40	46
Medium Flint $\theta=306°$, $A'=.000000102$		
0 min.	356μμ	351μμ
16020	205	223
28980	170	173
60240	130	112
Medium Flint $\theta=374°$, $A'=.0000106$		
0 min.	594μμ	578μμ
32	465	483
57	409	428
92	349	370
181	261	274
270	228	218
365	192	182
Medium Flint $\theta=390°$, $A'=.000040$		
0 min.	573μμ	568μμ
20	378	391
55	253	253
85	190	194
120	160	153
140	130	136

TABLE II.—*Continued.*

Experimental Results. Measurements of Release of Stress at Constant Temperature.

Time	Path diff., δ	δ, calc. by equation 7b.
Medium Flint $\theta = 406°$, $A' = .00017$		
0 min.	350μμ	345μμ
10	205	217
20	160	159
40	103	103
60	80	76
90	52	55
Heavy Flint $\theta = 375°$, $A' = .000029$		
0 min.	230μμ	225μμ
18	198	201
62	153	159
133	119	120
178	109	104
Heavy Flint* $\theta = 385°$, $A' = .000075$		
0 min.	205μμ	207μμ
31	135	140
60	115	107
122	72	71
166	47	58
Heavy Flint $\theta = 400°$, $A' = .00025$		
0 min.	145μμ	147μμ
15	100	95
19	90	87
27	70	74
58	50	47
89	30	34
168	19	20
Extra Heavy Flint $\theta = 350°$, $A' = .000046$		
0 min.	134μμ	130μμ
13	120	121
90	81	86
156	69	69
259	54	53
330	46	46
Extra Heavy Flint $\theta = 370°$, $A' = .00021$		
0 min.	108μμ	108μμ
29	65	65
59	43	46
98	37	35

The portions of the table marked with an asterisk (*) represent preliminary measurements which were made by the color-comparison method mentioned above. Except for some other preliminary observations the only measurements omitted from Table II were two series with ordinary crown glass which were obviously affected by an error in temperature.

Representation of Results.—It has generally been supposed that internal stress in a viscous substance is relieved at a rate which is proportional to the stress. If this were the case we could write

$$-\frac{dF}{dt} = const. \times F = mF$$

in which t denotes the time, F the force or stress. Integrating this equation and applying the initial condition that when $t = 0$, $F = F_0$, we have either

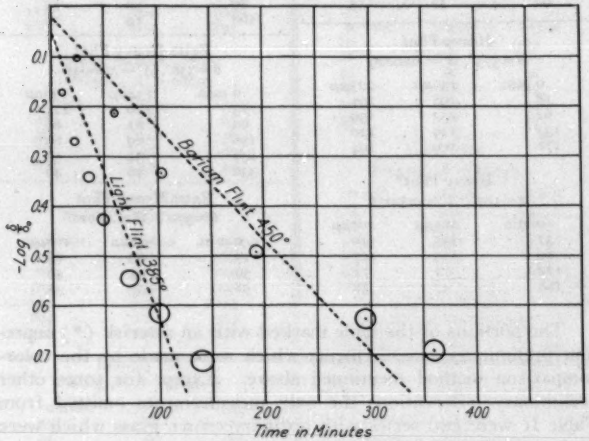
$$\frac{F}{F_0} = e^{-mt} \tag{4a}$$

or

$$\log F + m't = const. \tag{4b}$$

That is, the stress F would decrease exponentially with respect to time, and by plotting (for example, on semi-logarithm paper) $\log F$ against t for any series of observations, we would expect to obtain a straight line. Unfortunately, however, this expectation was not realized. In Fig. 8 two typical sets of measurements are plotted with $\log F$ as ordinate and t as abscissa. The smooth curve passing through the points is always convex toward the t-axis and deviates by more than the experimental error from any

FIG. 8.



Graphs showing for two typical cases $\log \frac{\delta}{\delta_0}$ plotted as ordinate against t, the time in minutes, as abscissa. The points do not lie in a straight line as would be the case if the release of stress proceeded according to Maxwell's relation. The radii of the circles representing the observations correspond in magnitude to an error of .5μμ.

straight line which can be drawn. It is evident, therefore, that the rate of diminution of F is not proportional to F. In the later stages the stress falls off more slowly than would be expected from its initial rate. Consequently we must seek some other law to represent the experimental results. In this connection it is interesting to note the remarks of Clerk Maxwell, in 1866, concerning the release of internal strain.[26] He wrote:

[26] Clerk Maxwell: Collected Papers. Vol. 2, p. 30. Univ. Press, Cambridge, 1890. See also *Phil. Trans.*, 157.

"* * * The phenomena of viscosity in all bodies may be described, independently of hypothesis, as follows:

"A distortion or strain of some kind, which we may call S, is produced in the body by displacement. A state of stress or elastic force which we may call F is thus excited. The relation between the stress and the strain may be written $F = ES$, where E is the coefficient of elasticity for that particular kind of strain. In a solid body free from viscosity, F will remain $= ES$, and

$$\frac{dF}{dt} = E\frac{dS}{dt}.$$

If, however, the body is viscous, F will not remain constant, but will tend to disappear at a rate depending on the value of F, and on the nature of the body. *If we suppose this rate proportional*[27] *to* F, the equation may be written

$$\frac{dF}{dt} = E\frac{dS}{dt} - \frac{F}{T},$$

which will indicate the actual phenomena in an empirical manner. For if S be constant,

$$F = ESe^{-\frac{t}{T}}$$

shewing that F gradually disappears, so that if the body is left to itself it gradually loses any internal stress, and the pressures are finally distributed as in a fluid at rest.

"If $\frac{dS}{dt}$ is constant,[28] that is, if there is a steady motion of the body which continually increases the displacement,

$$F = ET\frac{dS}{dt} + Ce^{-\frac{t}{T}}$$

shewing that F tends to a constant value depending on the rate of displacement. The quantity ET, by which the rate of displacement must be multiplied to get the force, may be called the coefficient of viscosity. It is the product of a coefficient of elasticity, E, and a time T, which may be called the 'time of relaxa-

[27] The italics are ours.

[28] We may also consider the condition for F constant, which leads to the equation:

$$E\frac{dS}{dt} = \frac{F}{T}.$$

For large values of t this becomes identical with the equation for $\frac{dS}{dt} = const.$

tion' of the elastic force. In mobile fluids T is a very small fraction of a second, and E is not easily determined experimentally. In viscous solids T may be several hours or days, and then E is easily measured. It is possible that in some bodies T may be a function of F * * *."

Maxwell was thus fully aware of the possibility that his assumption as to the proportionality of $\frac{dF}{dt}$ to F might not be justified in all cases. Our results clearly indicate that with glass, at any rate, the release of stress at constant temperature does not proceed according to the simple law expressed by equation (4), and consequently we must seek some other law to represent the experimental results.

Since the stress decreases less rapidly for small amounts of stress than would correspond to equation (4), it was thought that log F might be proportioned to some power of t other than the first power. Accordingly the equation

$$\log \cdot \frac{F_0}{F} = mt^b \tag{5}$$

was tried. The values of the constants m and b were obtained graphically by plotting log log $\frac{S_0}{S}$ against log t and drawing the best straight line through the points. This formula was found to represent the results satisfactorily, the deviations on the whole being no greater than the experimental error. The values of b, the power of t, varied between 0.5 and 0.7 for the different sets of observations.

Michelson [29] states that the behavior of any solid under stress may be considered as the resultant of the four separate effects: the elastic displacement, the elastico-viscous displacement, the viscous displacement, and the lost motion. The elastico-viscous displacement is represented by the formula $S_2 = A_2\ (1 - e^{-\alpha\sqrt{t}})$, or, rearranging the symbols, by

$$\log \frac{S_0}{S} = a\, t^{1/2},$$

which closely resembles our equation when $m = \alpha$ and $b = 1/2$.

But although equation (5) satisfactorily represents the data, it is inconvenient for calculation and especially for extrapolation.

[29] A. A. Michelson: *Proc. Nat. Acad. Sci.*, **3**, 319–323 (1917). *J. Geol.*, **25**, 405–410 (1917); **28**, 18–24 (1920).

A much better formula was derived from the arbitrary assumption that the rate of release of stress is proportional to the square of the stress; that is,

$$-\frac{dF}{dt} = ABF^2 \tag{6}$$

which by integration yields the rectangular hyperbola:

$$\frac{1}{F} - \frac{1}{F_0} = ABt \tag{7a}$$

in which F_0 is the stress at the time $t = 0$, and the product AB may be considered as one constant. The quantity directly measured is not F but δ, the optical path difference. To put the equation in convenient form for calculation, $F = \delta/Bl$ (see equations 3 and 4) is substituted in the above expression, yielding,

$$\frac{1}{\delta} - \frac{1}{\delta_0} = A't \tag{7b}$$

A' being the equivalent of A/l. Although this equation contains one constant less than equation (5), it represents the experimental results fully as well. It is also more convenient for calculation. Hence, without making any attempt to give a physical interpretation to this empirical relation, we have used it for interpolating and extrapolating our results. In Table II are included the values A', for the several series of measurements, and also the values of δ, calculated by equation (7b). It is evident that the agreement between δ "observed" and δ "calculated" is, on an average, within about 5$\mu\mu$, and it follows, therefore, that the above formula represents with satisfactory precision the release of stress in glass—at any rate, for the temperatures and with the amounts of stress with which it is convenient to measure the speed of annealing. Fig. 9, in which $\frac{1}{\delta}$ in $\mu\mu$ is plotted against t in minutes, shows graphically the order of agreement for three cases already plotted in a different way in Fig. 8.

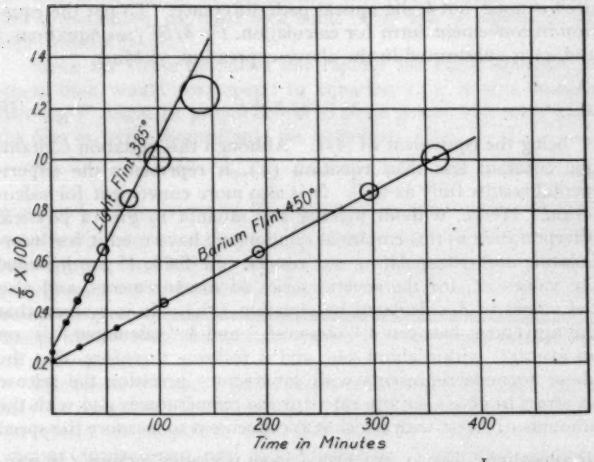
The values of A' for the various kinds of glass and for the various temperatures are collected in Table III. In the second column is tabulated l, the length of the slab in the line of sight, and in the third column [30] is A (the product of A' and l). The quan-

[30] For the computations involving A and A', t is in minutes, δ in $\mu\mu$ and Δn in $\mu\mu$ per cm.; that is, 10^7 times the difference in refractive indices.

tity A is a measure of the rate at which the stress, F, is released when the temperatures remain unchanged. A is also related to the fluidity or mobility; that is, to the reciprocal of the viscosity. Sometimes it is more convenient to describe the stress in terms of birefringence (*i.e.*, path difference per unit length). Substituting $\frac{\Delta n}{B}$ for F in equation (7a), we have

$$\frac{1}{\Delta n} - \frac{1}{(\Delta n)_0} = At \qquad (7c)$$

FIG. 9.



The same observations as those plotted in Fig. 8 are here plotted with $\frac{1}{\delta}$ as ordinate and t (the time) as abscissa. In this case the circles representing the observations lie, within the error of experiment, on a straight line. Here, as in Fig. 8, the radii of the circles indicate the shift in position due to an error of $5\mu\mu$.

The quantity A indicates (in optical rather than mechanical units) the variation of stress with time; it may therefore be called the annealing constant of the particular glass and at the temperature in question. Unlike A', this quantity is independent of the length of the glass specimen. On the other hand, if the law of release of stress happened to follow equation (4), the analogous equa-

tions containing F, δ or Δn would contain identical constants, *i.e.*, in that case, one and the same constant would determine the rate of disappearance of stress, or path difference, or birefringence.

TABLE III.

The Values of the Annealing Constant A for the Various Glasses at Various Temperatures.

Kind of glass	Temperature degrees C θ	Constant of equation 7b A'	Length of slab l	Annealing constant A $(=A' \times l)$
Borosilicate crown	480	.0000072	7.5 cm.	.000054
Borosilicate crown	500	.000022	7.5 cm.	.00017
Borosilicate crown	530	.00021	7.5 cm.	.0016
Ordinary crown	450	.0000034	10.8 cm.	.000037
Ordinary crown	470	.000024	10.8 cm.	.00026
Ordinary crown	490	.000049	10.8 cm.	.00053
Ordinary crown	500	.000105	10.8 cm.	.00113
Ordinary crown	515	.00040	10.8 cm.	.0043
Light barium crown	500	.0000113	7.5 cm.	.000085
Light barium crown	516	.000028	7.5 cm.	.00021
Light barium crown	540	.00020	7.5 cm.	.0015
Heavy barium crown	540	.0000062	7.5 cm.	.000047
Heavy barium crown	565	.000034	7.5 cm.	.00026
Heavy barium crown	590	.00047	7.5 cm.	.0035
Barium flint	450	.000022	7.5 cm.	.00017
Barium flint	470	.00013	7.5 cm.	.00098
Barium flint	490	.00031	7.5 cm.	.0023
Light flint	385	.000080	10.0 cm.	.00080
Light flint	400	.00017	10.0 cm.	.0017
Light flint	415	.00046	10.0 cm.	.0046
Medium flint	306	.000000102	7.5 cm.	.00000077
Medium flint	374	.0000106	7.5 cm.	.000080
Medium flint	390	.000040	7.5 cm.	.00030
Medium flint	406	.00017	7.5 cm.	.0013
Heavy flint	375	.000029	7.5 cm.	.00022
Heavy flint	385	.000075	7.5 cm.	.00056
Heavy flint	400	.00025	7.5 cm.	.0019
Extra heavy flint	350	.000046	7.5 cm.	.00034
Extra heavy flint	370	.00021	7.5 cm.	.0016

Although, as stated above, our results are satisfactorily represented by equation (7b), the fact was not disregarded that this is only an empirical equation, and like any other empirical equation, is not to be relied upon for expressing the behavior of glass at temperatures far removed from those at which the measurements were made. In order to determine the character of the agreement at much lower temperatures, a set of readings were taken with the light flint glass at about 300°, which is 85° below the lowest temperature at which the previous measurements were made. The glass anneals very slowly at this temperature, and

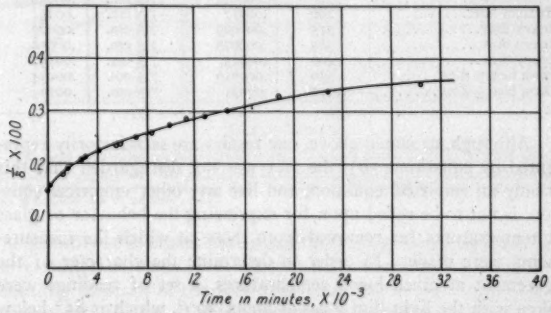
after three weeks nearly half of the original strain remained. The results are shown in Table IV and in Fig. 10. Unfortunately, the curve representing the points where $\frac{1}{\delta}$ is plotted against t

TABLE IV.

Special Experiment with Light Flint Glass at 300°—a Temperature at which the Release of Intense Stresses Proceeds very Slowly.

Time of reading	Elapsed time in minutes t	Optical path difference along middle δ	Temperature, degrees C
April 6, 2 P.M.	0	672	300.8
April 6, 4.30 P.M.	150	630	300.1
April 7, 10 A.M.	1200	555	298.7
April 7, 4.30 P.M.	1590	520	299.7
April 8, 10 A.M.	2640	478	299.5
April 8, 4.30 P.M.	3030	470	300.3
April 9, 11.15 A.M.	4155	445	300.1
April 10, 11.05 A.M.	5585	428	299.6
April 10, 4.30 P.M.	5910	420	300.2
April 11, 11.30 A.M.	7050	400	297.6
April 12, 9.30 A.M.	8370	385	299.1
April 13, 9.45 A.M.	9825	363	301.7
April 14, 10.30 A.M.	11310	350	300.0
April 15, 11.00 A.M.	12780	345	300.1
April 16, 4.30 P.M.	14550	333	299.9
April 19, 2.00 P.M.	18720	305	300.8
April 22, 9.40 A.M.	22780	297	301.0
April 27, 4.00 P.M.	30360	265	300.1

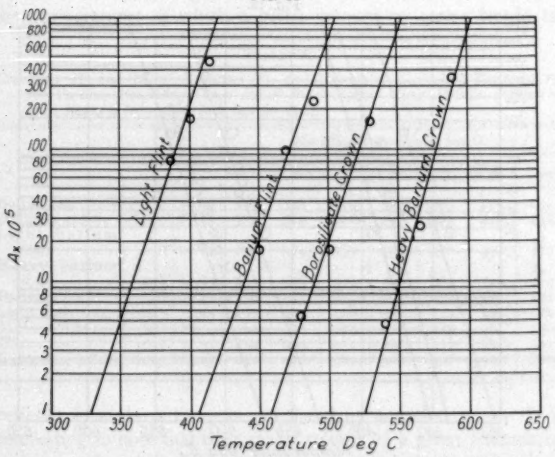
FIG. 10.



Graphical representation of data of special experiment with light flint glass at 300°. In this exceptional case (very low temperature and very slow release of stress) the graph of $\frac{1}{\delta}$ against t shows, particularly at the beginning, a considerable amount of curvature.

does not, in this case, prove to be a straight line, but is much curved at the beginning. This may be attributed, in large measure, to the circumstance that, whereas at higher temperatures a large amount of the initial strain is lost before the temperature is sufficiently constant for readings to be taken, at very low temperatures, on the other hand, the first reading is very nearly equal to the original strain. In this experiment, moreover, the initial strain happened to be somewhat higher than it was in the preced-

FIG. 11



Showing the variation of the annealing rate, A, with temperature. The logarithm of A, as ordinate, is plotted against the temperature as abscissa. The observations are well represented by straight lines.

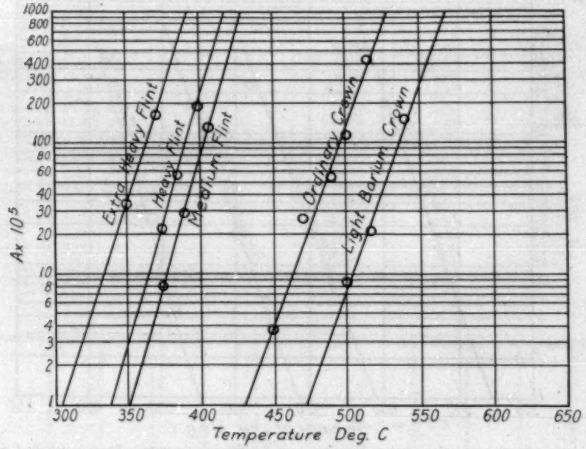
ing experiments. The fact that the temperature, as shown in Table IV, was not quite constant, probably does not vitally affect the character of the curve.

We must conclude, therefore, that at very low temperatures and for the initial part of the release of internal stress, formula (7) fails to represent the relation between stress and time. Nevertheless, we believe that within the temperature range, which is of the greatest practical importance, and except for the first part of the stress to be relieved, the above-mentioned formula gives

a useful and sufficiently accurate representation of the facts. At any rate, in the absence of a more satisfactory equation it will be convenient to use it, as shown below, in connection with the problems of glass-annealing.

We shall next consider the dependence of the annealing-constant upon the temperature. Twyman [31] has stated that the mobility of glass is a simple exponential function of the temperature. Our results confirm this conclusion, so that throughout the range

FIG. 12.



Similar to Fig. 11, but for the remaining five glasses.

of temperature covered by our experiments the variation of the annealing constant with the temperature is expressed by the equation

$$\log A = M_1 \theta - M_2 \qquad (8)$$

M_1 and M_2 are (positive) constants. In Figs. 11 and 12, $\log A$ is plotted against θ (which, contrary to the usual convention, represents centigrade, not absolute, temperature). The points for any

[31] F. Twyman: "The Annealing of Glass." *J. Soc. Glass Techn.*, 1, 62 (1917).

one glass, as a rule, lie on a straight line from the position of which the constants M_1 and M_2 may be determined.

When M_1 and M_2 are known for each type of glass it is possible to calculate by equations (7) and (8) the time required at any temperature to reduce the stress in any glass from any initial to any final value. In other words, the annealing time under any prescribed conditions can be readily computed from two or more observations for each kind of glass at each of two or more temperatures. In Table V are assembled the values of M_1 and M_2 for the nine kinds of glass investigated. This table also shows the temperatures at which a given amount of stress would be

TABLE V.

Constants M_1 and M_2 of Equation (8), and Calculated Annealing-Temperatures for Various Annealing Times (when Birefringence along Middle of Slab is to be Reduced from 50μμ to 2.5μμ per cm.).

Kind of glass	M_1	M_2	Annealing temperatures, deg. C.						
			2 min.	10 min.	1 hr.	5 hrs.	1 day	1 wk.	1 mo.
Borosilicate crown	0.030	18.68	599	575	549	526	503	475	454
Ordinary crown..	.029	17.35	573	549	522	498	475	446	424
Light barium crown.....	.032	20.10	606	584	559	538	516	490	470
Heavy barium crown.....	.038	24.95	638	619	599	580	563	540	524
Barium flint.....	.028	16.28	556	531	503	478	454	424	401
Light flint.....	.033	15.92	461	439	416	395	374	348	329
Medium flint....	.038	18.34	464	445	425	407	389	366	350
Heavy flint.....	.037	17.51	454	435	414	395	377	354	337
Extra heavy flint	.033	15.03	434	412	389	368	347	321	302

relieved in a given time, as calculated by equation (7c). It is interesting to note that the time of release of a given fraction of the stress (or path difference) depends upon the magnitude of the initial stress. Thus it takes only one-half as long to change the stress (in optical units) from 800μμ to 400μμ as from 400μμ to 200μμ. The annealing times given in Table V are for the specific case of reduction of stress from 50μμ per cm. to 2.5μμ per cm., which, as will appear later, is of especial importance in the annealing of optical glass.

Comparison with the Results of Other Investigators.—Schott was one of the first to study the annealing of glass. In order to ascertain the best conditions for cooling various kinds of glass without the production of stress, highly stressed cylinders of the

glass were held at different temperatures for 20 to 24 hours.[32] The cylinders were 10 to 15 mm. in diameter and 20 to 40 mm. in length, and had the ends ground and polished for examination between crossed nicols. By observing the number of colored rings before and after the heating, Schott determined the lowest temperature at which there was an undoubted diminution of stress. For the three optical glasses investigated these temperatures were: "Ordinary" crown, 400–410°; "ordinary" flint (similar to our medium flint), 350–360°; borosilicate crown, 400–410°. It is difficult to compare these results with ours because the compositions of the glasses do not correspond exactly to those we have used, and also because the initial internal stress is not recorded. Nevertheless, it is interesting to note, for the glasses most nearly resembling ours (namely, the medium flint and the borosilicate crown), the diminution in stress, according to our results, after twenty-four hours at the given temperatures. Taking 500$\mu\mu$ per cm. as a fair value for a "high" stress and using equations (7c) and (8), we find that for medium flint 85 per cent. of the stress would have been relieved after twenty-four hours at 350°, and for borosilicate 15 per cent. after twenty-four hours at 400°. The value for borosilicate glass agrees much better with Schott's conclusions than that for flint.

Grenet[33] measured (1) the highest temperature from which glass strips could be suddenly cooled without the introduction of stress, and also (2) the temperatures at which the stress was seen to disappear when the glass was heated about 100° per minute. For ordinary crown, these two temperatures were, respectively, 573° and 641°. The results of Grenet, while interesting, can hardly be said to have a quantitative significance.

An elaborate research on the annealing of glass was carried out by Zschimmer[34] and later by Zschimmer and Schulz.[35] The plan of the investigation consisted of three main divisions: (1) A series of determinations of the strain produced when a block of glass is suddenly cooled from a given temperature θ to room

[32] O. Schott: *Z. Instrumentenkunde*, 11, 330–337 (1891).

[33] L. Grenet: *Bull. Soc. d'encouragement*, 3, 1507 (1898).

[34] E. Zschimmer: *Arch. f. phys. Chem. Glases.* (*Monatsbeilage des Sprechsaal*) 1, Nos. 2 and 3 (1912).

[35] E. Zschimmer and H. Schulz: *Ann. Phys.* (4) 42, 345–396 (1913).

temperature (20°); (2) the measurement of the time required for the disappearance of the stress when the glass is maintained at various temperatures; and (3) the determination of the dependence of these factors on the chemical composition of the glass.

The earlier measurements (by Zschimmer) were made with centimetre-cubes of two kinds of glass, one a very light barium crown and the other a flint similar in composition to our medium flint. The strain produced by sudden cooling from various temperatures is recorded by means of photographs of the cube between crossed nicols. The annealing times at various temperatures, as given for the two glasses, were obtained by bringing the cubes rapidly up to the desired temperature and noting the time when the birefringence was judged to have completely disappeared. In the more extensive measurements of Zschimmer and Schulz the birefringence was measured quantitatively by a method which gave very sharp and narrow interference bands. Results are given for the strain produced by the sudden cooling of about 25 different kinds of optical glass in the form of blocks, usually $4 \times 4 \times 24$ mm. in size. The relation between F, the stress (birefringence) and θ, the temperature from which the glass is cooled, is expressed by the empirical equation

$$(\theta_0 - \theta)(F + F_0) = C$$

in which θ_0 is a certain temperature called the "softening temperature" and F_0 and C are constants. This formula is not applicable for temperatures immediately below θ_0, while above the "softening temperature" the strain produced is practically independent of the temperature.

The data of Zschimmer and Schulz give valuable information concerning the minimum temperatures at which strain may be introduced by cooling. Unfortunately, however, the chemical compositions of the glasses are not specified (except for the flints, the lead contents of which are given), and the cooling rates are not recorded, and could be ascertained only by supplementary experiments. On the other hand, the results of Zschimmer[36] on the rate of disappearance of stress at constant temperature suffer from the disadvantage inherent in any method whereby the bire-

[36] Zschimmer: *Loc. cit.*, p. 12.

fringence is observed only qualitatively and not actually measured.

The first investigator to attack in a really comprehensive manner the problem of glass-annealing was Twyman,[37] who realized that the viscosity of the glass was the property of fundamental importance. The mobility or viscosity was measured by supporting a strip of glass at one end and loading it at the other with a known weight, and measuring the rate of fall of the weight when the strip was maintained at known constant temperatures. From the stress, F, the rate of fall, $\frac{ds}{dt}$, and the known value of the modulus of elasticity E, the "time of relaxation" T was calculated from the relation [38]

$$T = \frac{F}{E}\frac{dt}{ds}$$

Then assuming that $\frac{dF}{dt}$ is proportional to F, the value of T was used with Maxwell's equation,

$$\frac{F}{F_0} = e^{-\frac{t}{T}} \qquad (9)$$

to calculate the rate of release of stress in unannealed glass.

As mentioned above, the assumption on which this equation is based is not entirely justified, and, at least for the amounts of stress usually encountered in optical glasses, the equation fails to fit the facts. We should expect, therefore, to find material differences between the annealing temperatures, as determind by Twyman's method, and those determined by direct observation of the rate of release of stress in unannealed glass. A comparison of the two methods for the same kind of glass would be extremely interesting, but Twyman gives in his paper only a single observation for a glass of unstated composition.

The temperatures at which strain disappears rapidly when glass is heated at a rate of a few degrees per minute was determined by Morey and Wright at the plant of the Bausch and Lomb Optical Company. For four glasses, similar but not identi-

[37] F. Twyman: "The Annealing of Glass." *J. Soc. Glass Techn.*, 1, 61–73 (1917).

[38] See footnote on page 617. T may be defined as the time which would be required to reduce the stress to zero if dF/dT remained constant.

cal with the glasses described in Table I, the temperatures were as follows:[39]

Ordinary crown	540°	(573)
Light barium crown	600°	(606)
Borosilicate crown	590°	(599)
Light flint	[<500°]	(461)

These values show a rough agreement with the figures in parenthesis which are the temperatures (taken from Table V) at which, according to our measurements, the stress would be reduced in two minutes to the very small amount, 2.5$\mu\mu$ per cm., if the initial stress be assumed to be 50$\mu\mu$ per cm. Morey and Wright also state that in borosilicate crown the strain disappears in a few hours at 550°; over night at 510° and not in 16 hours at 480°. From equations (7c) and (8) and the values of M_1 and M_2 in Table V we note that borosilicate glass would be annealed (from 50$\mu\mu$ to 2.5$\mu\mu$ per cm.) at 550° in 0.96 hours, at 510° in 15.2 hours, and at 480° in 120 hours.

The temperatures of rapid release of internal stress have also been measured by English and Turner,[40] who used cylinders 8 mm. in diameter and 30 mm. long, with plane polished ends. The stress as observed qualitatively by the optical method was found to disappear rapidly at the temperatures given in Table VI. The first 13 glasses in the table are lime-soda glasses of varying composition. No. 10, which most nearly resembles our ordinary crown, anneals rapidly at 581°, while according to Table V the annealing temperature (for $t = 2$ min.) of the ordinary crown is 573°. The results of English and Turner, like the results of the other observers mentioned above, do not furnish complete information concerning the annealing process, but data such as those in Table VI afford a valuable comparison between the annealing constants of various glasses.

The most recent investigation of the annealing of glass is

[39] From a private communication to the authors. The greatest difference in composition between these glasses and those used by us occurs with the ordinary crown. That used by Morey and Wright contained 10.2 per cent. ($CaO + BaO$), and 20.7 per cent. ($Na_2O + K_2O$), while ours contained 12 per cent. (CaO) and 15 per cent. ($Na_2O + K_2O$).

[40] Solomon English and W. E. S. Turner: *J. Soc. Glass Techn.*, **2**, 90–102 (1918); **3**, 125–128 (1919).

that carried out by Tool and Valasek.[41] The "annealing temperatures" were determined by heating glass cylinders 2 cm. in diameter at a rate of 2° per min. and noting the temperature at which a diminution in birefringence was first perceptible. Six of the nine optical glasses investigated by Tool and Valasek resemble in composition those described in this paper. It is difficult, however, to compare their results with ours except to note that their "annealing temperatures" for the six glasses are in some cases higher and in other cases much lower than the temperatures (as given in the fourth column of Table V) at which, according to our results, strain disappears very rapidly.

TABLE VI.

Determinations by English and Turner of the Temperature of Rapid Release of Stress in Glass.

No.	CaO	Chemical composition [a]				"Annealing" temperature
		Na_2O	Al_2O_3	B_2O_3	SiO_2	
1	0.21	25.34	0.24	.....	74.05	483
2	1.50	23.80	0.20	.....	73.92	490
3	2.61	23.00	0.21	.....	74.08	492
4	3.81	21.50	0.28	.....	74.07	503
5	4.50	20.78	0.38	.....	73.78	512
6	6.26	19.38	0.58	.....	73.18	526
7	7.45	17.20	0.30	.....	74.41	538
8	8.16	16.00	0.31	.....	74.99	552
9	9.36	14.88	0.42	.....	74.96	562
10	10.38	14.22	0.45	.....	74.59	581
11	11.68	13.02	0.38	.....	74.93	601
12	18.17	12.72	1.41	.....	66.71	608
13	17.38	11.22	0.50	.....	69.73	613
14	7.00	11.50[b]	10.00	7.00	64.00	630
15	2.00[c]	8–9[b]	10.00	7.00	70.00	635
16	.....	10.00[b]	2.00	23.00	65.00	585–590
17	17–30[d]	11–15[b]	.....	.....	57–64	450–460

[a] Small amounts of MgO, Fe_2O_3, and As_2O_3 are omitted from the table.
[b] Na_2O and K_2O.
[c] ZnO.
[d] PbO.

Tool and Valasek determined the rate of relaxation of stress at various temperatures both by the optical method (diminution of birefringence) and by mechanical methods (stretching or bending of rods), and calculated the "relaxation time," T, from

[41] A. Q. Tool and J. Valasek: *Trans. Am. Inst. Min. Met. Eng.*, 1945–1952 (1919). *Bull. Bureau of Standards*, 15, 537–571 (1920) (Sci. Paper No. 358).

Maxwell's relation (see equation 9 above). They find that the values of T obtained by the two methods do not agree and that in general T is not independent of the initial stress; *i.e.*, larger stresses relax more quickly and smaller stresses more slowly than would be expected from the extrapolation. This observation is in accord with our conclusion (see above) that $\frac{dF}{dt}$ is proportional not to F but to F^2. Tool and Valasek have also made some interesting observations on the absorption and evolution of heat in glass at those temperatures at which softening begins. This heat effect was observed in 1905 by Day and Allen in connection with a study of the crystallization phenomena of borax glass. Day and Allen state that:

"On every occasion when the borax glass was heated rapidly, either powdered or in the solid block, a slight but persistent absorption of heat appeared in the same region [490° to 500°] and continued over some 20°, after which the original rate of heating returned." [42]

The same effect has also been observed by So [43] for various glasses and found to occur at about the temperature at which stress disappears rapidly. In this same range of temperature So observed also a longitudinal contraction of glass rods upon heating but not upon cooling. Tool and Valasek observed an evolution of heat when the glass was cooled as well as an absorption of heat on heating. This effect begins at about the same temperature as that at which an increase in the thermal expansion was found by C. G. Peters. They have suggested that since the thermal effects occur at about the softening point of the glass, the annealing temperature of glasses may be estimated by determining the temperatures at which the heat absorption or evolution takes place.

The change with temperature of the rate of release of stress was found by Tool and Valasek to follow Twyman's empirical relation (see equation 8 above), and for the various glasses the rate of annealing was found to double for each 7° to 9° rise in temperature; whereas Twyman found the interval to be 8°, and, as stated above, according to our measurements this temperature increment varies between 8° and 11° for the various glasses.

(To be concluded.)

[42] A. L. Day and E. T. Allen: "The Isomorphism and Thermal Properties of the Feldspars." Carnegie Institution of Washington, Publ. No. 31, p. 34.

[43] Masamichi So: *Proc. Tokyo Math. Phys. Soc.*, 9, 425-442 (1918).

Isotopy.—The general history and theory of isotopy is discussed by J. F. CORRIGAN (*Chem. News*, 1920, cxxi, 88, 102). He states that one of the earliest indications of the theory was pointed out in 1887, when Crookes noted the closeness of the atomic weights of the rarer elements, and put forward the view that these might be modifications of a single element. He separated yttria into several components, each marked by a different spectrum, but differing only minutely in chemical properties. For such conditions, Crookes proposed the title *meta-elements*. The suggestion did not meet with much success. The discovery of the phenomena of radio-activity gave a new impulse to speculations in this field. The first suggestion of explanation was in Soddy's theory of atomic disintegration, the old idea of the atom being, however, retained. Abegg's theory of valency came in as a further explanation of the observed phenomena. In this it is assumed that each element possesses two kinds of valencies, normal and contra, which are electrically different, the normal valencies being positive in the metals and negative in the non-metals. Corrigan discusses at some length these questions. The term "isotope" as applied to elements which although possessing different atomic weights fall into the same place in the periodic table, was first suggested by Soddy. For elements, such as mesothorium II and radiothorium, which, although possessing similar atomic weights, fall into different groups, the term "isobars" has been suggested, but it is to be hoped will not be adopted, as the word has already been appropriated in meteorology. Isotopy in lead has been especially the subject of investigation.

In conclusion, Corrigan says that the facts that have recently been made known have revived the "whole-number" theory, first suggested in the early part of the last century, by William Prout. Elements that show fractional atomic weights on even the most careful estimation may be mixtures of several modifications, but a question is at once suggested, as to why these modifications always occur in such proportions that the atomic weight of the element is so nearly the same in all cases so far determined. The subject is evidently in its incipiency, and before long interesting and striking developments may be expected.

H. L.

THE SCATTERING OF X- AND γ-RAYS.*

BY

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INTRODUCTION.

In 1912, the writer [1] published evidence which left practically no doubt that X- and γ-rays were of the same nature. That this nature is that of light has since been proved by the researches of Laue [2] and Friedrich and Knipping.[3] X- and γ-rays differ from ordinary light because of their much smaller wave-lengths, the work of Moseley [4] and Rutherford and Andrade [5] showing that we can take 10^{-7} to 10^{-10} cms. as rough limits for the wave-lengths of these rays. W. H. Bragg and W. L. Bragg,[6] Moseley and Darwin,[7] Duane,[8] and others have shown that the spectrum of any beam of X-rays consists of a continuous one with a line spectrum superimposed on it. That given in Fig. 1 is not supposed to fit any actual case, but suffices to draw attention to these facts. Each "line" is probably of definite width and forms in itself a continuous spectrum of narrow range. The ordinary continuous spectrum is due to what is called the independent or general radiation, the line spectrum to the characteristic X radiation of the material emitting the rays.

It is necessary to draw attention to the method of obtaining wave-lengths, introduced by W. L. Bragg.[9] In this method, a narrow beam of X-rays from the source S (see Fig. 2) is allowed to fall on a natural face of a crystal C at a glancing angle θ. A beam of wave-length λ will in general be reflected from the crystal.

* Communicated by Prof. A. S. Eve, Corresponding Member, Associate Editor.

[1] Gray, *Roy. Soc. Proc., Series A*, vol. lxxxvii, p. 489, 1912.

[2] Laue, *Kön. Bay. Ak.*, p. 303, 1912.

[3] Friedrich and Knipping, *Kön. Bay. Ak.*, p. 311, 1912.

[4] Moseley, *Phil. Mag.*, **27**, p. 703, 1914.

[5] Rutherford and Andrade, *Phil. Mag.*, **28**, p. 263, 1914.

[6] Bragg, W. H., and Bragg, W. L., *Roy. Soc. Proc., Series A*, vol. lxxxviii, p. 428, 1913.

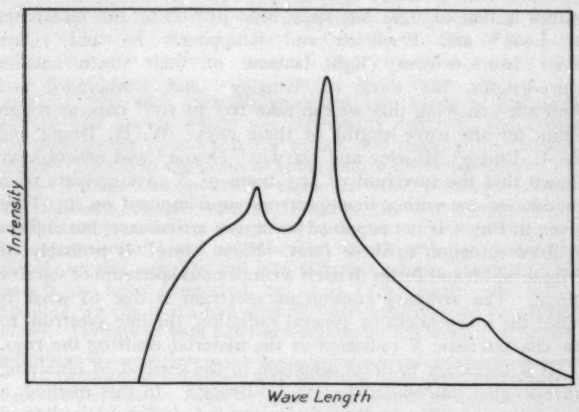
[7] Moseley and Darwin, *Phil. Mag.*, **26**, p. 210, 1913.

[8] Duane, *Phys. Rev.*, **6**, p. 166, 1915.

[9] Bragg, W. L., *Camb. Phil. Soc.*, vol. xvii, p. 43, 1912; *Nature*, Jan. 23, 1913.

As the constituents of the crystal are arranged in layers or planes parallel to the face of the crystal, $\lambda = 2d \sin \theta$, where d = distance between successive planes. The waves from successive planes reinforce each other much in the same way that, in an ordinary diffraction grating, waves from successive lines of the grating reinforce each other. The modern theory of white light, of which a very full account is given in Schuster's " Optics," maintains that,

FIG. 1.



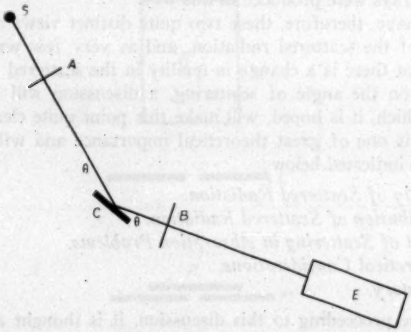
when this light falls on a grating, the periodicity in a beam, diffracted in a definite direction, is manufactured by the grating. Similarly, we believe that the periodicity in a reflected beam of X-rays is manufactured by the crystal used. With this limitation, we will speak of the average wave-length of a beam of X-rays. Rutherford and Andrade [10] have shown that penetrating γ-rays have a much smaller average wave-length than ordinary X-rays, but there is otherwise no distinction between the two types of rays.

If a beam of X-rays (the primary rays) strikes any substance (the radiator), three types of rays are emitted in all directions

[10] Rutherford and Andrade (*loc. cit*).

from it, scattered X-rays, characteristic X-rays and electrons moving at high speed, which we can call secondary β-rays. Scattered X-rays do not depend in quality on the nature of the radiator, at least only to a small extent. They do depend in quality, however, on that of the primary rays. They have been examined by Barkla,[11] Barkla and Ayres,[12] Crowther,[13] Sadler and Mesham,[14] and others. The views of most writers about the quality of scattered X-rays have been well summed up by G. W. C.

FIG. 2.



Kaye in his book on "X-rays." "All substances, when exposed to a beam of X-rays, themselves give out X-rays, which are identical with the primary rays in quality, and can in fact be conveniently regarded as so many unchanged primary rays, which have been merely scattered or deviated by the substance."

Sadler and Mesham, however, considered that scattered rays were less penetrating than primary rays and the writer,[15] using as primary rays the γ-rays of radium $(B+C)$, showed that the scattered rays were of quite a different type to that of the primary rays, the quality of the rays de-

[11] Barkla, *Phil. Mag.*, **7**, p. 543, 1904; **21**, p. 648, 1911.
[12] Barkla and Ayres, *Phil. Mag.*, **21**, p. 270, 1911.
[13] Crowther, *Roy. Soc. Proc. Series A*, vol. lxxxv, p. 29, 1910.
[14] Sadler and Mesham, *Phil. Mag.*, **24**, p. 138, 1912.
[15] Gray, *Trans. Roy. Soc. Canada*, May, 1913; *Phil. Mag.*, **26**, p. 611, 1913.

pending also on the angle of scattering. Florance[16] had previously shown that the scattered rays in this case became less and less penetrating than the primary rays, the greater the angle of scattering. The usually accepted explanation[17] of this phenomenon is that, as the primary rays are heterogeneous, softer rays are scattered relatively more strongly at larger angles than harder rays. This has very little to do with the result, however, the softer rays being produced from harder rays during the process of scattering. In a later paper Florance[18] recognized that soft rays were produced in this way.

We have, therefore, these two quite distinct views about the quality of the scattered radiation, and as very few writers are aware that there is a change in quality in the scattered rays, depending on the angle of scattering, a discussion will be given below, which, it is hoped, will make this point quite clear. The problem is one of great theoretical importance and will be discussed as indicated below:

Quality of Scattered Radiation.
Distribution of Scattered Radiation.
Effect of Scattering in Absorption Problems.
Theoretical Considerations.
Summary.

Before proceeding to this discussion, it is thought advisable to draw attention to the figures in the table below obtained from

TABLE I.

Type of Radiation	Average Wave Length	Mass Absorption Coefficient				
		Carbon	Aluminum	Iron	Copper	Lead
Iron X-rays K series	1.8×10^{-8} cm.	10.0	88.5	66.1	95.1	about 400
Silver X-rays K series	0.53×10^{-8} cm.	0.46	2.5	17.4	22.7	about 70
Reflected X-rays	0.244×10^{-8} cm.	....	0.493	2.88	3.84	11.2
Hard γ-Rays of radium D	.....	0.116	0.380	2.80	....	11.2
Reflected X-rays	0.160×10^{-8} cm.	....	0.178	0.64	0.79	1.88
X-rays excited in lead by β-rays of radium E	.....	0.074	0.124	0.64	....	3.7 to 0.16
γ-rays of radium C	$<10^{-9}$ cm.	0.041	0.041	0.041	0.041	0.042

[16] Florance, *Phil. Mag.*, **20**, p. 921, 1910.

[17] Compton, A. H., *Phys. Rev.*, **14**, p. 20, 1919; see also Florance (*loc. cit.*), and Oba, *Phil. Mag.*, **27**, p. 601, 1914.

[18] Florance, *Phil. Mag.*, **27**, p. 225, 1914.

information given by Barkla and Collier,[19] the writer,[20] Rutherford and Richardson,[21] Rutherford and Andrade,[22] and Hull and Rice.[23] By reflected X-rays, we mean X-rays obtained by reflection from crystals.

Apparent discrepancies will be noted in the figures for aluminum. These, however, are due to the fact that absorption coefficients have been obtained by two different methods, which we will call method 1 and method 2. In method 1,

FIG. 3.

(see Fig. 3), the rays from the source S pass through holes in the lead screens L and M, so that characteristic and scattered X-radiations emitted from the absorption plate A, of thickness x, say, cannot enter the electroscope E. If I_0 = the original intensity, I_1 the intensity of the rays after passing through the absorption plate and we write $I_1 = I_0 e^{-\mu_1 x}$, then μ_1 = the average

[19] Barkla and Collier, *Phil. Mag.*, **23**, p. 987, 1912.
[20] Gray, *Roy. Soc. Proc. Series A*, vol. lxxxvii, p. 489, 1912.
[21] Rutherford and Richardson, *Phil. Mag.*, **25**, p. 722; **26**, p. 324, 1913.
[22] Rutherford and Andrade (*loc. cit.*).
[23] Hull and Rice, *Phys. Rev.*, **8**, p. 326, 1916.

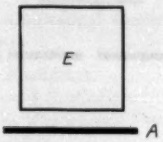
absorption coefficient of the rays in the plate A. The absorption is due to different processes and it is usual to write $\mu_1 = \tau + \sigma$. The coefficient τ gives a measure of the absorption due to the ejection of secondary β-rays and to the formation of X-rays characteristic of the absorbing material. On the other hand, σ gives a measure of the absorption of the primary rays due to scattering in the absorber. To compare different materials we write

$$\frac{\mu_1}{\rho} = \frac{\tau}{\rho} + \frac{\sigma}{\rho}$$

where ρ = the density of the plate A. The quantity $\frac{\mu_1}{\rho}$ is called the mass absorption coefficient and $\frac{\sigma}{\rho}$ the mass scattering coefficient.

In method 2, (see Fig. 4), we have no plates such as L and M

FIG. 4.



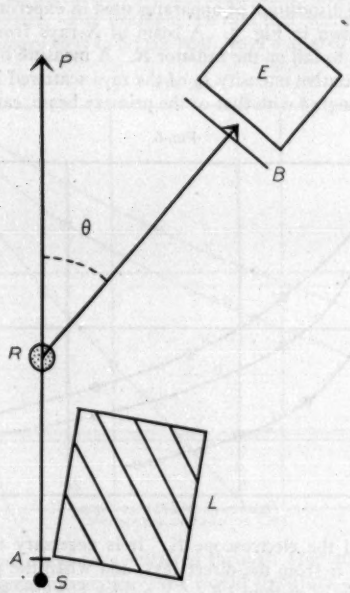
defining the rays, and the plate A is placed under the electroscope E. If, now, I_2 = the intensity of the rays after passing through A we may write

$$I_2 = I_0 \varepsilon^{-\mu_2 x},$$

where μ_2 is again called the absorption coefficient, although, strictly speaking, this is not accurate. As, in this case, emergent scattered radiation enters the electroscope E, it is evident that μ_2 is less than μ_1 the correct value. This fact is brought out by the figures in the above table (those for γ-rays and X-rays excited by β-rays

having been obtained by the second method), and also in some given by Ishino.[24] The method, however, is a very useful one and if σ is small compared with τ, μ_2 is practically equal to μ_1. Writing in general $I = I_0 e^{-\mu x}$ we see that if μ is constant,

FIG. 5.



$\log I + \mu x = \log I_0$, so that if $\log I$ is plotted against x the resulting curve is a straight line.

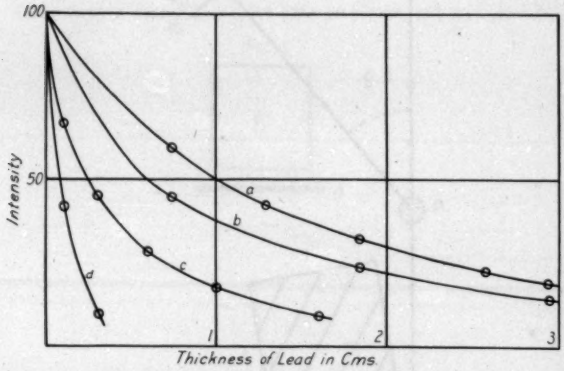
The table shows that, as the average wave-length of a beam decreases, its penetrating power on the whole increases. It is also desired to draw attention to the fact that, while carbon absorbs the γ-rays of radium *D* about three times as much as the γ-rays of radium *C*, lead absorbs the former rays over two hundred times as much.

[24] Ishino, *Phil. Mag.*, 33, p. 140, 1917.

QUALITY OF THE SCATTERED RADIATION

When we wish to compare the qualities of two different beams, we should obtain their spectra, but this is often impracticable. In experiments on the scattering of X-rays, such a comparison has invariably been made by absorption measurements. The disposition of apparatus used in experiments on scattering is shown in Fig. 5. A beam of X-rays from the source S is allowed to fall on the radiator R. A measure of the quality, and of the relative intensity I_θ of the rays scattered in a direction making an angle θ with that of the primary beam, can be obtained

FIG. 6.



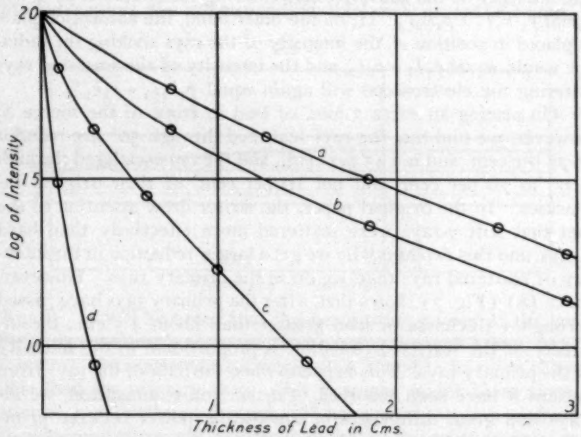
by means of the electroscope E. It is necessary to screen the electroscope E from the direct rays, and when the primary rays are the γ-rays of radium $(B+C)$, a thick block of lead L is used for this purpose. In the writer's experiments, the active material S consisted of 15 milligrams of radium bromide enclosed in a lead cylinder 1.7 mm. thick.

Some of the results obtained are shown in the curves of Figs. 6 and 7. Curve (a) refers to the absorption of the primary rays, curve (c) to the absorption of the rays scattered through 50°, the absorbing material being placed in front of the electroscope, and curve (d) refers to the absorption of rays scattered through 110°. Curve (b) enables us to find the relative intensity of the

rays scattered through 110°, after different thicknesses of lead are placed in front of the source S (position A). The corresponding curve for 50° would lie between curves (a) and (b). In Fig. 6 the intensity is plotted against the thickness of absorbing material, and in Fig. 7 the logarithm of the intensity to the base 10 is plotted instead.

That the scattered rays are less penetrating than the primary is at once evident. For example, we find that 3 mm. of lead reduces the primary rays to 80 per cent., rays scattered through 50°

FIG. 7.



to 45 per cent., and rays scattered through 110° to 10 per cent. of their original intensities. We would therefore expect that, if no modification in the rays is produced by scattering, an extra 3 mm. of lead placed in front of the active material would again reduce the relative intensities of the three types of radiation to 80 per cent., 45 per cent., and 10 per cent., respectively. The following analysis will make this clearer, and will prove, with the information given later, that the scattered radiation we are examining is not due to reflection at crystalline facets inside the radiator.

We will suppose that the primary radiation consists of two types, one soft, one hard, of intensities I_1, I_2, respectively. We will also suppose that no change in either type is produced by scattering. If these rays fall on the radiator R, the intensity of the rays scattered through an angle θ, say, and entering the electroscope E (Fig. 5) may be written equal to $k_1I_1 + k_2I_2$. The coefficients, k_1,k_2, will depend both on the type of radiation and on the absorption of both primary and scattered rays in the radiator. If we have a lead plate which transmits a fraction p_1 of soft rays, p_2 of hard rays and place it in position B (see Fig. 5), the intensity of the scattered rays entering the electroscope E will equal $p_1\,k_1I_1 + p_2k_2I_2$. If, on the other hand, the absorption plate is placed in position A, the intensity of the rays striking the radiator would equal $p_1I_1 + p_2I_2$, and the intensity of the scattered rays entering the electroscope will again equal $p_1k_1I_1 + p_2k_2I_2$.

On placing an extra 3 mm. of lead in front of the source S, however, we find that the rays scattered through 50° are reduced to 75 per cent. and not 45 per cent., and the rays scattered through 110° to 70 per cent. and not 10 per cent. of their original intensities. In the original paper, the writer drew attention to the fact that soft γ-rays were scattered more effectively than hard γ-rays, and this explains why we get a larger reduction in the intensity of scattered rays than we do in the primary rays. However, curve (*b*) (Fig. 7) shows that, after the primary rays have passed through a thickness of lead greater than about 1.5 cm., the intensity of the scattered radiation is proportional to the intensity of the primary rays. This happens when the bulk of the rays from radium *B* have been absorbed. Further, on examination, we always find great differences in penetrating power between primary and scattered rays, similar to those indicated by curves (*a*), (*c*), and (*d*). This variation of quality with the angle of scattering, and the fact that it is approximately independent of the nature of the radiator, show that the effect we have observed is not due to the formation of characteristic radiations in the radiator. We conclude, therefore, that in some way an ordinary beam of γ-rays is changed in quality when scattered, the change depending on the angle of scattering.

The writer had intended to use, as primary rays, X-rays reflected from a crystal, but it was not until after demobilization last year, that he was able, through the kindness of Sir William

Bragg and the British Scientific and Industrial Research Council, to carry out further experiments at University College, London. In the time at his disposal he was not able to obtain a reflected beam of sufficient intensity to work with satisfactorily. However, one that was approximately homogeneous, according to measurements of penetrating power and wave-length, was obtained by filtering X-rays through a sheet of tin. This beam was tested as follows. After it had passed through various thicknesses of aluminum, the percentage transmitted by a sheet of aluminum 1.63 mm. thick was found. This percentage has been plotted against the corresponding thickness passed through in

FIG. 8.

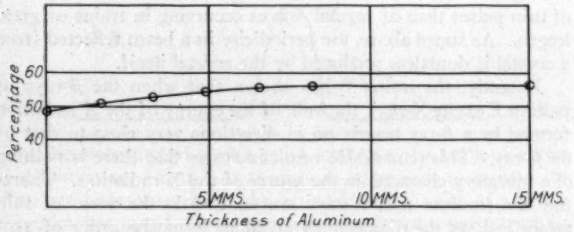


Fig. 8. It will be noted that the penetrating power of the beam becomes very nearly constant after passing through 7 mm. of aluminum. The scattered rays were again found to be more absorbable than the primary rays. For example, under these circumstances, rays scattered through 35° have an absorption coefficient in aluminum 6 per cent. greater than that of the primary rays; rays scattered through 70°, an absorption coefficient 12 per cent. greater; and rays scattered through 110°, one 18 per cent. greater. The increase is thus approximately proportional to the angle of scattering. It also appeared to be independent of the thickness of aluminum passed through.

These experiments, which will be discussed in greater detail in a later paper, verify the previous results obtained with γ-rays, although, in the latter case, the comparative softening of the scattered rays is much more marked. Curves (*a*) and (*c*) (Fig. 7) indicate that, in this case also, scattered rays are always less penetrating than primary rays no matter how much absorbing ma-

terial the rays pass through. This point is of importance, as it indicates that the smaller wave-lengths in the spectrum of the primary rays would be absent in the spectrum of the scattered rays.

The results we have obtained would be explained if we could always look on a beam of X- or γ-rays as a mixture of waves of definite frequencies, and if rays of a definite frequency were altered in wave-length during the process of scattering, the wave-length increasing with the angle of scattering. But we may not always be justified in looking on a beam of X-rays in this way or, in other words, we may not always be able to estimate the properties of such a beam by Fourier analysis. We have very little idea of the actual mechanism by which X-rays are produced from β-rays, but it seems probable that X-rays consist rather of a series of thin pulses than of regular waves occurring in trains of great length. As stated above, the periodicity in a beam reflected from a crystal is doubtless produced by the crystal itself.

Recently, the writer [25] has shown that when the β-rays of radium *E* excite X-rays, the bulk of the energy of the X radiation formed by a β-ray travels on in directions very close to that of the β-ray. This remarkable result indicates that there is nothing of a vibratory character in the source of the X radiation. Therefore we consider that X-rays are emitted in the form of thin pulses and, as the diameter of an atom is of the order of 10^{-8} cms., the thickness of a pulse would be of that order.

The following calculation may be of interest. Suppose we pass a current of 1.6 milliamperes through an X-ray tube. This would mean that

$$\frac{4.8 \times 10^{-4}}{4.8 \times 10^{-19}} \text{ or } 10^{15}$$

electrons would hit the anticathode per second. Experiment indicates that only a small fraction of these electrons give rise to X-rays. Let us suppose that, at most, one in a hundred do so. 10^{14} pulses would then be emitted per second, and as such pulses travel at the rate of 3×10^{10} cms. per second the average distance between pulses would be 3×10^{-4} cms. The average distance between pulses is, therefore, much greater than the average thickness of a pulse. The actual form of a pulse we do not know, but for purposes of illustration we can imagine it to be of the shape indicated by Fig. 9, in which, at some definite time, the electric displacement in

[25] Gray, *Proc. Roy. Soc.*, Series A, Vol. 86, p. 513, 1912.

the pulse is supposed plotted against the distance from its origin, the pulse travelling on unchanged in form when not passing through matter. If two similar pulses pass over a point simultaneously, then the thickness of the combined pulse will be the same as before, but its intensity will be four times that of a single pulse just as is the case when two waves of the same length and in the same phase reinforce each other. If the two pulses are slightly out of step, the resultant pulse will be slightly thicker and less penetrating and the resultant intensity will be less than four times that due to a single pulse.

Later on we will consider, briefly, from a theoretical point of

FIG. 9.

view, the scattering of such a pulse, and also of a train of waves of definite wave-length. It appears to be possible to explain the effect we have observed if the primary rays consist of a series of pulses, but not if the primary rays consist of a wave train of definite wave-length. That reflected rays differ from ordinary scattered radiation is evident from an experiment of Moseley's and Darwin's.[26] They found that when the same absorption plate was placed in positions *A* and *B* (see Fig. 2) the electroscope reading was the same in both cases. When we are measuring ordinary scattered radiation and use an absorbing screen in which a negligible amount of its characteristic radiation is excited, the intensity as registered by the electroscope is invariably greater when the plate is placed in position *A*. We have seen above, for example, that in the case of the scattering of the γ-rays of radium, for an angle of scattering of 110° and an absorption plate of lead 3 mm. thick, the intensity is about seven times as much when the lead is placed in position *A*. Finally, the writer understands that further experiments at University College, London, have proved directly that a wave train of definite wave-length is not altered in wave-length by scattering.

[26] Moseley and Darwin (*loc. cit.*).

DISTRIBUTION OF THE SCATTERED RADIATION.

In the case of ordinary X-rays, the distribution of the scattered radiation in most cases is similar to that given by Fig. 10, where I_θ is plotted against θ, the angle of scattering. For values of θ greater than 90°, $\frac{I\theta}{I_{90°}}$ is nearly equal to but somewhat less than $(1+\cos^2\theta)$. For angles less than 90°, $\frac{I_\theta}{I_{90°}}$ is nearly always greater than $(1+\cos^2\theta)$. An average value of $\frac{I_{30°}}{I_{90°}}$ is about 2.10 instead of 1.75.

When the γ-rays of radium $(B+C)$ are used as primary rays, very penetrating secondary β-rays are emitted from the radiator, and it is necessary to have some absorbing material in front of the electroscope E to absorb these rays. In Florance's original experiments 3 mm. of lead was used, and the distribution apparently found by him then is given in Fig. 11. We have seen above, however, that this thickness of lead cuts down some types of scattered radiation much more than others and thus this curve is to some extent misleading. Using a carbon plate to absorb these β-rays and correcting for absorption in the radiator and carbon plate, the writer found that for carbon,

$$\frac{I_{30°}}{I_{90°}} = 2.10$$

and

$$\frac{I_{130°}}{I_{90°}} = 1.20$$

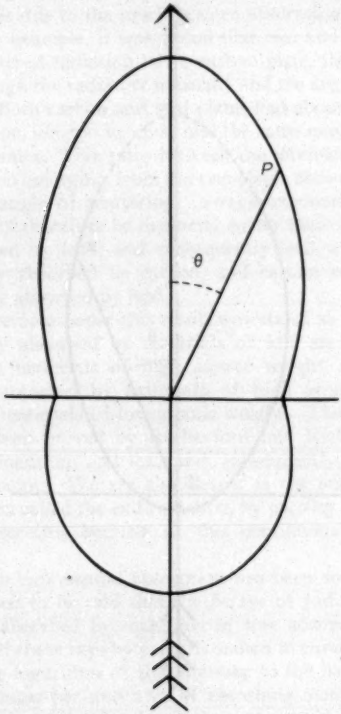
These values do not differ very much from those obtained with certain types of X-rays. They indicated for the first time that less radiation was scattered through 90° than any other angle, a point of considerable importance.

The writer believes that there are no marked differences in the distribution of the scattered radiation, whether the primary rays are soft X-rays or penetrating γ-rays. As a matter of fact, for values of θ between 30° and 110°, a range over which the writer has worked, $I_\theta/I_{90°}$ varies very little, whatever the type of primary rays. This shows that if the rays are not altered in quality by scattering, the penetrating power of the scattered rays should vary very little with the angle of scattering.

EFFECT OF SCATTERING IN ABSORPTION EXPERIMENTS.

In this section, absorption according to the second method described above will be considered. A consideration of the table and of the results given above, makes it evident that the

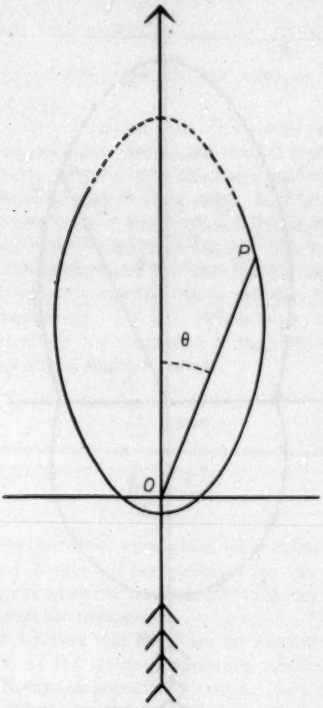
FIG. 10.



following processes are at work, when an ordinary beam of X- or γ-rays passes through matter. In the first place, we have the greater relative absorption of the softer rays, and in the second place, the reproduction of soft rays by the scattering

of the primary rays. Ultimately we would expect the two effects to balance each other, and then the absorption would become exponential. Mrs. Soddy, Soddy and Russell,[27] have shown this to be the case with the γ-rays of radium $(B+C)$ as primary rays,

FIG. 11.



and with lead as absorbing material, for a range in thickness of 2 to 22 cms. With the same primary rays, Russell[28] found the

[27] Soddy, Mrs., Soddy and Russell, *Phil. Mag.*, 19, p. 225, 1910.
[28] Russell, *Proc. Roy. Soc. Series A*, vol. lxxxviii, p. 75, 1912.

absorption in mercury exponential for a range in thickness of 1 to 25 cms.

With the γ-rays of radium $(B+C)$ as primary rays, it can be shown that much less scattered radiation escapes, under similar circumstances, from a lead plate than from a corresponding carbon plate. This is due to the much greater absorption of softer rays in lead. For example, it was found that two and one-half times as much scattered radiation left a carbon plate, the primary rays passing through the radiators normally and the angle of scattering being 50°. Both carbon and lead plates had about the same area of cross section, *viz.*, 90 sq. cms., and the same mass per unit area, *viz.*, 10 grammes. This ratio between the intensities of the scattered radiation emerging from the two plates becomes greater, the greater the angle of scattering. γ-rays exponentially absorbed by carbon will therefore be distinctly softer than γ-rays exponentially absorbed by lead, and consequently lead will harden rays exponentially absorbed by carbon, and carbon will soften rays exponentially absorbed by lead.

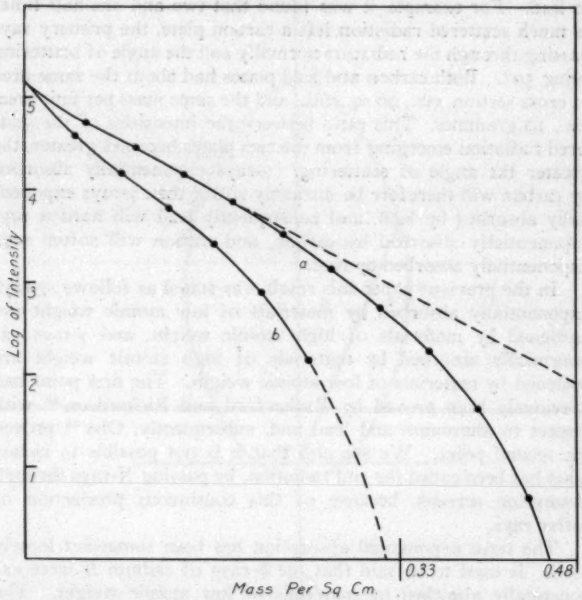
In the previous paper this result was stated as follows: γ-rays exponentially absorbed by materials of low atomic weight are hardened by materials of high atomic weight, and γ-rays exponentially absorbed by materials of high atomic weight are softened by materials of low atomic weight. The first point had previously been proved by Rutherford and Richardson [29] with respect to aluminum and lead and, subsequently, Oba [30] proved the second point. We see also that it is not possible to isolate what has been called the end radiation, by passing X-rays through absorption screens, because of this continuous production of softer rays.

The term exponential absorption has been somewhat loosely used. It used to be said that the β-rays of radium *E* were exponentially absorbed by materials of low atomic weight. The absorption of these rays by paper is shown in curve (*a*) (Fig. 12) in which the logarithm of the intensity to the base 10 is plotted against the mass per unit area of absorbing material. The rays appear to be exponentially absorbed over a certain range, but afterwards the absorption increases, and no rays pass through a thickness of paper greater than one corresponding to a mass per unit area of 0.48 gramme q. p. Curve (*b*) shows the absorption of

[29] Rutherford and Richardson (*loc. cit.*).
[30] Oba (*loc. cit.*).

β-rays reflected from a lead plate, and indicates that fast β-rays are reduced in velocity when scattered through large angles. This curve has been obtained for the writer by Miss A. V. Douglas, who is continuing the experiments. β-rays have a range because they lose energy, owing to ionising some of

FIG. 12.



the atoms through which they pass. The writer has often wondered whether γ-rays have a range, or whether they will pass through any thickness of material provided the initial intensity is large enough. This important question has apparently been answered by Russell,[31] who found that the γ-rays of radium $(B+C)$ could not be observed through 27 cms. of mercury, no matter how sensitive he made his measuring apparatus. His

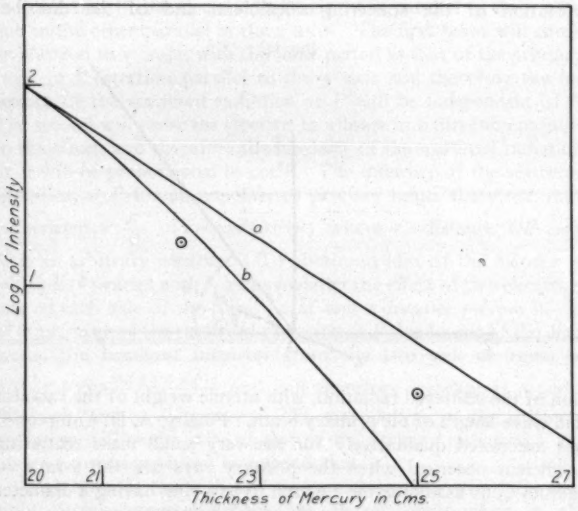
[31] Russell (*loc. cit.*).

result is shown in curve (*b*) (Fig. 13). The second point does not fit the curve because the corresponding intensity of the rays was too small to be measured accurately. The points should lie on the straight line, curve (*a*).

THEORETICAL CONSIDERATIONS.

The theory, which has given the best explanation of the properties of scattered radiation, was originally introduced by Sir

FIG. 13.



Joseph Thomson.[32] In this theory, when an electromagnetic pulse passes over an atom, the electrons in it are accelerated and the secondary pulses caused by the acceleration of these electrons form the scattered radiation. Thomson considered that the forces exerted by the primary pulses on the electrons were large compared with the forces tending to keep them in their equilibrium

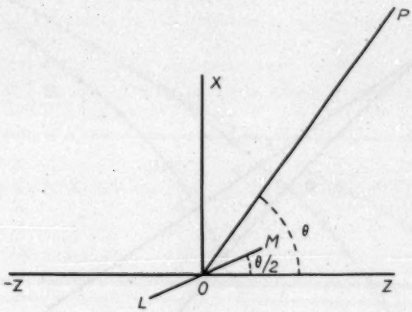
[32] Thomson, J. J., "Conduction of Electricity Through Gases," 2d Edition, p. 321.

positions, and also that the electrons scattered independently of each other. Under these circumstances it can be proved that

$$I_\theta \text{ is proportional to } (1 + \cos^2\theta)$$

The next advance was made by D. L. Webster,[33] who considered that the electrons did not scatter independently of each other. He also believed that the scattered radiation should be less penetrating than the primary radiation. C. G. Darwin,[34] taking the primary rays to be of definite wave-length, obtained an expression which gave a rough qualitative explanation of the variation of the scattering coefficient, and of the distribu-

FIG. 14.



tion of the scattered radiation, with atomic weight of the radiator and wave-length of the primary beam. Finally, A. H. Compton[35] has accounted qualitatively for the very small mass scattering coefficient observed when the primary rays are the γ-rays of radium *C*, by assuming the electron to be a ring having a diameter comparable with the wave-length of the primary rays.

The analysis given below will bring out these points and also the differences in the scattering of rays of definite wave-length and of a single pulse. First we will suppose the primary rays to be of wave-length λ. In Fig. 14 the direction of the incident radiation is given by –ZOZ. We will suppose that the rays pass

[33] Webster, D. L., *Phil. Mag.*, **25**, p. 234, 1913.
[34] Darwin, C. G., *Phil. Mag.*, **27**, p. 315, 1914.
[35] Compton, A. H. (*loc. cit.*).

through an atom with nucleus at O. It is desired to find the variation of I_θ with θ, the angle of scattering. We will take rectangular axes at O, and a point P in the zx plane such that OP makes an angle θ with OZ. LOM represents the section of a plane perpendicular to the zx plane and making an angle $\frac{1}{2}\theta$ with the yz plane. Finally we will suppose that the average distance of the electrons in the atom from the plane LOM, $= p$, a distance that will be independent of the angle θ.

We can get the effect of an unpolarized beam by considering two separate polarized beams of equal intensities, in one of which the direction of the electric displacement is parallel to the y axis and in the other parallel to the x axis. The first beam will cause an electron to vibrate, with the same period as that of the primary rays, in a direction parallel to the y axis and therefore the intensity of the scattered radiation at P will be independent of θ. The second will cause the electron to vibrate in a direction parallel to the x axis and therefore the intensity of the scattered radiation at P will be proportional to $\cos^2\theta$. The intensity of the scattered radiation at P for an unpolarized primary beam, therefore, may be written $= \frac{K}{r^2}(1+\cos^2\theta)F(\theta)$ where $r =$ distance OP and K is an arbitrary constant. To obtain an idea of the manner in which $F(\theta)$ varies with θ, let us consider the effect of two electrons, one on each side of the plane LOM and a distance p from it. If $a^2 =$ intensity of the scattered radiation at P due to one of the electrons, the resultant intensity from the two will be equal to $2a^2\left\{1+\cos\frac{(8\pi p \sin\frac{1}{2}\theta)}{\lambda}\right\}$, and will therefore increase as p and θ diminish, and as λ increases. The wave-length of the scattered radiation will be the same as that of the primary radiation. The above expression shows in general that:

(1) Mass for mass, heavy atoms scatter more effectively than light atoms, since electrons are nearer each other in the heavy atoms.

(2) X-rays of long wave-length are scattered more effectively than rays of short wave-length.

(3) $F(\theta)$ diminishes with θ and therefore that $I_{(\omega^\circ - \alpha)}$ is greater than $I_{(\omega^\circ + \alpha)}$.

When the wave-length of the incident radiation is comparable with the diameter of the electron, we can imagine that O is the centre, and our two scattering centres equal parts of the

electron, each being a distance p from the plane LOM. From this we get Compton's result that, in such a case, the scattering is less effective than when the wave-length of the incident radiation is large. For example, the resultant intensity from two such scattering centres would be proportional to

$$2\left\{1+\cos\frac{(8\pi p\sin\frac{1}{2}\theta)}{\lambda}\right\}$$

instead of being proportional to 4.

When the primary rays consist of a series of independent pulses we can prove as before that I_θ may be written $= \frac{K}{r^2}(1+\cos^2\theta)f(\theta)$. In this case the difference in path between scattered pulses from our two electrons will be $4p\sin\frac{1}{2}\theta$ and for very small valves of p and θ, the intensity of the resultant scattered radiation will be nearly four times that from a single electron. We can see, as before, that in general:

(1) Mass for mass heavy atoms scatter more effectively than light atoms.

(2) Thick pulses are scattered more effectively than thin pulses.

(3) $f(\theta)$ diminishes with θ.

In addition, the thickness of the scattered pulse will depend on θ and will be larger the greater the angle of scattering. It would also appear as if the quality of the scattered radiation depended in general on the atomic number of the scattering atom. Again, when the thickness of the pulse is comparable with the diameter of an electron, the electron will not scatter the pulse as effectively as it would, if the thickness of the latter was large compared with the diameter. Conclusions (1), (2), (3) have been verified by experiment.

It appears, therefore, as if we must draw a distinction between the scattering of a train of waves of definite wave-length and of a pulse. Now Rutherford and Andrade have shown that the γ-rays of radium $(B+C)$ have decided line spectra, and yet we have this surprising change in quality produced by scattering. This shows that experiments on the scattering of characteristic X-rays are very necessary, for it is very difficult to believe that such rays consist of a series of pulses. The conclusion, however, that the bulk of γ radiation consists of a series of pulses may perhaps be justified.

The discussion we have given of experiments and theory is

to be regarded as a preliminary one only. It shows that the scattering of X-rays is not as simple a process as has generally been believed, and that a great deal of work needs to be done before we can properly understand the problem. Having recently obtained the necessary apparatus, the writer will continue experiments on the subject, in the hope that such experiments will add to our knowledge of radiation and atomic structure.

Before concluding this section, it is perhaps advisable to say why we have not considered the possible effect of secondary β-rays in producing "scattered" radiation. Such β-rays may excite X-rays (a) in their expulsion from atoms (b) in collisions with other atoms. Only a very small proportion of scattered radiation can, however, be formed in this way. As a rule, so many more β-rays are produced per unit mass in material of high atomic weight, and are so much more effective in producing X-rays in such materials, that we would expect a much greater variation of the mass scattering coefficient with atomic weight than we actually find. For example, the γ-rays of radium D are scattered just as effectively by carbon as by lead, and yet they must excite nearly fifty times as many β-rays in a small mass of lead as in the same mass of carbon. It is not necessary to give other reasons.

SUMMARY.

1. It has been proved, when an ordinary beam of X- or γ-rays, (*i.e.*, one not obtained by reflection from crystals), is scattered, that the rays scattered in any definite direction are of quite a different type to that of the primary rays. This type depends on that of the primary rays, the angle of scattering, and possibly on the nature of the scattering material. The effect is such that the scattered rays become less and less penetrating than the primary rays, the greater the angle of scattering.

2. The distribution of the scattered radiation for all types of X and γ radiation is similar, less radiation being scattered through 90° than in any other direction.

3. A discussion is given on the effect of scattering in absorption problems.

4. Theoretically, it appears possible to explain the results of experiment on the hypothesis that X-rays consist of a series of pulses, and evidence is given that this should be the case. When the primary rays are rays of definite wave-length reflected from a crystal, the scattered rays should be of the same wave-length.

Composition of Ancient Bronzes from the Far East.—MASUMI CHIKASHIGE (*J. C. S.*, 1920, cxvii and cxviii, 917) states that bronzes are the most suitable materials from which to obtain information in regard to ancient metallurgical methods. Brass articles are not so ancient as bronze, the latter dating from before the tenth century. Excavated objects are always covered with rust, which is generally removed before making analyses, but the author thinks this inadvisable. In bronze a selective oxidation takes place in the order: copper, lead, tin. The composition of the rust will differ from that of the object, being richer in copper. Montelius gave in 1900 the following analysis to two similar Egyptian rings:

Copper	79.51	16.23
Tin	9.65	75.66

The first ring seems not to have undergone much change, but the other has lost much copper by oxidation. The author's method is to remove earthy matter but to analyze rust and metal together, but even this method is unsatisfactory when a partial solution or disintegration of the surface material has occurred. A series of analyses is given, among which is that of a white bronze mirror from the first century containing on an average as its principal ingredients, copper, 67; tin, 27; and lead, 6. The author was able to make a good mirror with these constituents. White bronze is very hard, the figures on the backs of such mirrors consisting of deeply cut lines have resisted wear for several thousand years. Arrow heads were found to contain principally copper and tin, with small amounts of antimony, iron and nickel. A Japanese bell that dates from the tenth century is principally copper and tin, but with notable amounts of lead and antimony and a small amount of nickel. Chinese coins, current from the fifth to the eighth century, B.C., show much difference in composition, the principal ingredients being copper, tin and lead with, in a few cases, appreciable amounts of iron and arsenic. Corean bronze articles were found to be largely copper and tin. This alloy is quite resistant to rusting.

H. L.

Rainfall in Hawaii. (*U. S. Geological Survey Press Bulletin* No. 457, October, 1920.)—An inch a day is the average rainfall in the upper Waipio Valley, Hawaii, which makes it one of the areas in the world where the rainfall is heaviest. On the other hand, the rainfall on some of the slopes of Hualalai, on the same island, is only 20 inches a year. The only surface streams on the island are along the northeast coast between Hilo and Kohala. Waipio River, according to the Survey, has been partly developed for irrigation.

THE MEASUREMENT OF GRAININESS IN PHOTOGRAPHIC DEPOSITS.*

BY

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WHEN a photographic deposit is examined under the microscope, it is found to be made up of a large number of minute particles consisting of metallic silver which have been reduced from the silver halide by the action of the developer. It is necessary to employ a relatively high magnification in order to resolve clearly the individual particles or grains composing this silver deposit. The size of such grains varies over a considerable range, the homogeneity of grain size being dependent upon the particular type of emulsion. Measurements have shown that these grains vary in diameter from approximately 0.5 microns in slow plates up to from 1 to 10 microns in high-speed plates. The distribution of these grains through the gelatine in which they are embedded is not absolutely uniform, there being in many cases a marked tendency for these grains to occur in groups or clumps of from five to twenty grains. Further, in some cases, these aggregates also tend to agglomerate, thus causing a further lack of homogeneity in the appearance of the deposit.

Considerable research work has been done by various investigators relative to the size of grain in the undeveloped plate as well as in the deposit resulting from the development of the exposed silver halide. Practically all of this work deals with the size of the ultimate silver halide crystals or the metallic silver particles, and with the relative proportion of grains of various sizes occurring in various emulsions. In some cases a developed deposit may appear grainy (that is, lacking homogeneity) to the unaided eye. The cause of this is almost invariably due to an agglomeration or grouping of the clumps made up of several of the ultimate silver particles which of themselves are so small as to be entirely beyond the resolving power of the unaided eye.

* Communicated by Dr. C. E. K. Mees. Communication No. 99 from the Research Laboratory of the Eastman Kodak Company.

When a deposit is viewed under magnifications insufficient to make just visible the ultimate grains, a lack of homogeneity is apparent which is due primarily to the presence of the first order clumps or aggregates composed of a few of these metallic silver particles. Under such conditions, the agglomeration of these clumps ceases to have any appreciable effect on the grainy appearance of the deposit because the magnification is sufficient to separate widely the agglomeration centres. When the magnification is increased still further so that the individual silver grains are easily visible, the graininess existing is due in a great measure to these grains themselves. It will be seen, therefore, that the lack of homogeneity in a photographic deposit depends upon various causes, according to the magnification under which the deposit is observed.

In speaking of grain, the scientific investigator usually refers to the ultimate silver halide particles of the emulsion, or to the minute particles of metallic silver resulting from the reduction of the halide during development. A complete specification of grain as thus defined is given by stating the apparent diameter of the particles and the relative number of each size present in a given volume or mass of the emulsion. A curve plotted with the number of grains of a given size as ordinates and the grain size as abscissæ values results in a curve of the probability type; the exact shape of which is a function of the particular emulsion considered.

Now, when a case of lesser magnification is considered, such as exists, for instance, in the projection of motion pictures, or in the making of enlargements, the lack of homogeneity is due not to the ultimate grains themselves, but to aggregates of these grains composed of a relatively small number of the ultimate particles. To this type of non-homogeneity the word "graininess" is applied in order that it may be clearly distinguished from the effect produced by the resolution of the individual grains under much higher magnifications. In this paper, therefore, whenever the term "graininess" is used it should be understood as a designation of that effect of inhomogeneity exhibited by the photographic deposits due to the presence of groups or clumps of silver particles. The grainy appearance, which can be observed by the unaided eye, is due to further agglomeration of these aggregates and should properly be referred to as graininess of the second order. It is evident, therefore, that there are three phases in the non-homogeneity of a photographic deposit, (*a*) graininess due to the existence

of the individual particles of silver, (*b*) graininess due to clumping of these particles, and (*c*) graininess due to the agglomeration of the clumps. It should be understood that these phases are not separated by any distinct line of demarcation, but merge by imperceptible gradations into each other. *Graininess* in reality is a subjective factor, and may be defined as the sensation or impression of non-uniformity in a photographic deposit, produced upon the consciousness of the observer when such a deposit is viewed. This impression is the result not only of the size of the grains of which the deposit is composed, but also the distribution and arrangement in groupings of various kinds.

The graininess of a plate of given performance is dependent on the grain characteristics of the emulsion. The magnitude and distribution of the grains in a given emulsion is determined by various factors operating during its manufacture. The distribution of grains is not subject to positive control; at best it will be only a probability distribution. To secure the lowest graininess in a photo-sensitive material of a given performance with respect to speed, latitude, contrast, and so forth is one of the problems of the emulsion maker. It will be the concern of the plate user to ascertain if any part of the treatment he is likely to give the photographic material received by him from the manufacturer has an influence on graininess, and if this is found to be the case, to determine the optimum condition for the minimizing of graininess. The factors which the plate user has largely under control are the exposure of the plate, the nature of the reducing agent, and other constituents of the developer and their concentration in the developing solution, the temperature and duration of development, and various conditions that enter during the after-treatment of the negative, in washing, fixing, drying, intensification, or reduction and the like.

Experimental inquiries on these points have already been made by various investigators. Schaum [1] found that a variation in the exposure carries with it a corresponding variation in the size and dimensions of the silver grains. M. M. A. and L. Lumiere and A. Seyewetz [2] state that overexposure evidently reduces the size of the grains. They found, moreover, that the grains deposited by the developing agents ordinarily used in practice are of practically constant magnitude, but that two developers, paraphenylenediamine and orthoamidophenol, used under special conditions,

give a grain much finer than that produced by the usual method of development. As to the other constituents of the developer, they found that an excess of alkali or of alkaline bromide appears to produce a very slight increase in the size of the grain. The concentration, temperature, and duration of action of developers appeared to them to have no apparent influence on the size of grains of reduced silver. On the other hand, Wallace [3] states that " the original grain-particles of the silver bromide are by prolonged development considerably enlarged by reason of the formation of group particles, which are relatively enormously increased in size, so that a method of rapid development (provided that the developer is compounded not to give too great a contrast) is the means of obtaining a more definitely uniform deposit of particles, which most nearly approach the size of the original silver bromide. The relative grain size of various deposits was determined by Lumiere and Seyewetz by dissolving off the gelatine coating on the negative in hot water, and after shaking, examining the silver particles under the microscope or by means of photomicrographs. Wallace examined the silver *in situ* by the same means.

Many other investigations on the general subject of grain have been made, but no attempt will be made at this time to give a complete bibliography of this literature. The standpoint from which this subject is approached in the present paper is quite different from that of previous investigators, and the few references given above are mentioned in order to emphasize the difference between the two points of view and also because of the interest attached to a comparison of the results of investigations on " grain " with those of this paper on " graininess."

These investigations of grain while providing valuable information as to the size of the ultimate particles do not yield data adequate for the specification of the magnification to which a given deposit may be subjected without exhibiting an appearance of graininess, nor do they make it possible to classify the various emulsions in relation to their graininess characteristics. In view of the very extensive use of photographic materials for purposes which require subsequent enlargement of the photographic deposit, it seemed highly desirable to develop a method whereby the graininess factor might be measured and specified numerically. Such a method will permit of the determination of the relative merits of various emulsions and the effects of the various steps

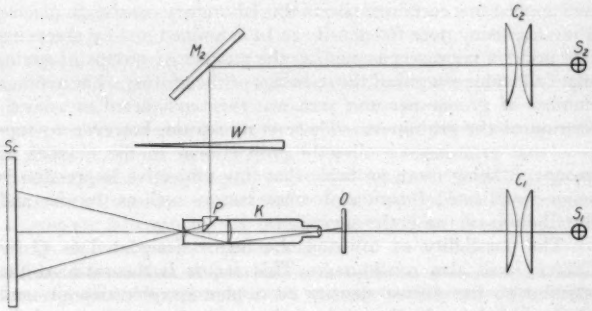
in the production of the ultimate result, such as development, fixing, washing, drying, etc. The only method for the determination of graininess at the time this work was undertaken was entirely qualitative in character. This consisted of the preparation of a series of prints made at a fixed degree of magnification from the positive under consideration. These were then examined by a number of observers, and judgments rendered as to the relative graininess of the various prints. By averaging the individual opinions, final decision as to the proper order of arrangement in the series was obtained. Such a method while giving some information as to the graininess characteristics is not quantitative and is not at all satisfactory. Another method suggested and applied to a certain extent in this laboratory consists in placing a mesh grating over the density to be examined and by observing this under a microscope counting the number of groups of grains that fall under several of the openings of the grating. The average number of groups per unit area was then considered as a specification of the graininess. There is no reason, however, to suppose that graininess is directly proportional to the number of groups, it being more probable that this subjective impression is some complicated function of other factors such as the size and distribution of the grain aggregates.

The possibility of utilizing the factor designated as Q by Callier[4] was also considered. This factor is the ratio of the specular to the diffuse density of a photographic deposit, and hence must be some function of the grain characteristics of the deposit. It is probable, however, that the value of this factor is dependent more largely upon the size of the ultimate particles than upon the distribution of these particles in aggregates and groups of aggregates, and since the preliminary experiments made in an effort to connect Q with graininess did not yield promising results, it was decided to adopt a more direct method for the determination of graininess.

After careful consideration a method based on a principle more closely parallel with the actual conditions existing in the observation of grainy photographic deposits appeared to give greater promise. The fundamental assumption upon which this method is based is that the graininess of a deposit is directly proportional to the distance at which the appearance of graininess becomes just imperceptible, provided that all other factors upon

which depend the ability of the eye to distinguish lack of homogeneity are constant. For instance, consider an enlargement of a photographic density, the degree of enlargement being such that the lack of homogeneity (*i.e.*, graininess) is readily apparent when observed at, let us say, ordinary reading distance (*i.e.*, 30 cm.). Now, if the viewing distance be increased gradually, a point will finally be reached at which this lack of homogeneity will disappear and the entire print appear to be of uniform brightness, free from all visible texture. The distance at which this condition exists may be taken as a numerical measure of the graininess

FIG. 1.



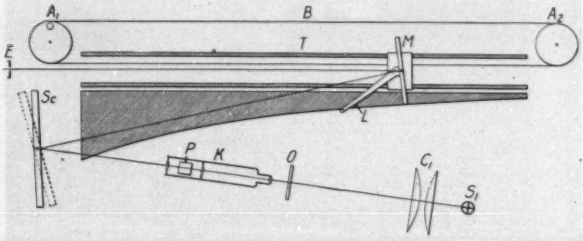
of the enlargement. If another enlargement made to the same degree of magnification be viewed under precisely similar conditions the distance at which graininess disappears when compared to the distance at which graininess disappeared in the previous case will provide a numerical specification of the relative graininess of the two deposits. The determinations made in this manner would, however, be subject to large errors; the readings would vary from day to day and be dependent upon the individual characteristics of the observer.

In order that such a method be satisfactory, it is necessary to control the conditions of observation so that the results obtained shall depend only upon the variations in the photographic deposits considered. It is evident that the distance at which a non-homogeneous surface appears to be homogeneous in texture is a function of

the resolving power of the observer's eye, and hence all factors upon which depend this resolving power must be kept constant during observations or the method so arranged that errors due to variations in resolving power may be eliminated. It is thought that in the method developed in this investigation the influence of all variable factors that operate to invalidate the results have been very largely eliminated, and that graininess has been expressed in terms of an easily reproducible standard.

The diagrams shown in Figs. 1 and 2 show the arrangement of the essential parts of the instrument designed and built for the measurement of graininess, Fig. 1 being a side elevation and Fig. 2 a plan view. Light from the source S_1, passes through a

FIG. 2.

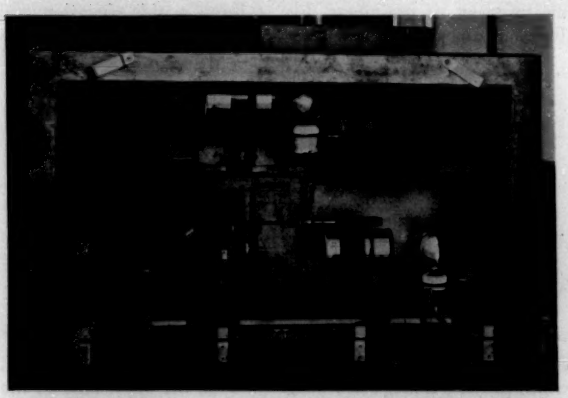


condenser C_1, to the object O, thence through the microscope K, which projects a magnified image of O on the upper half of the diffusely reflecting screen Sc. Light from a companion source S_2 passes through the condenser C_2 and is reflected by the mirror M_2 through a neutral wedge W and into the prism P, by which it is again reflected to the lower half of the screen. The observer places his eye at the artificial pupil E (Fig. 2) and views the image projected on Sc in a mirror M, which may be moved along the track T by means of a belt B passing over the pullies A_1 and A_2, and to which it is attached. A lever L acting on a template maintains the mirror, easily movable about its vertical axis, in such a position that the image of Sc reflected in it is always centrally in the line of vision of the observer.

S_1 and S_2 are 6-volt, 72-watt concentrated tungsten filament electric lamps, connected in series and working from line current

through a variable lampbank resistence. An ammeter indicates the current passing at any moment, and a voltmeter is so arranged that readings may at any time be taken of the voltage at which either of the lamps is working. The condenser C_1 is mounted in a tube with helical thread, and may be easily moved along its axis in such a way as to control the amount of light that falls on O. C_2 is fixed. The object O may be passed before the objective of the microscope by means of a mechanical stage. The micro-

FIG. 3.

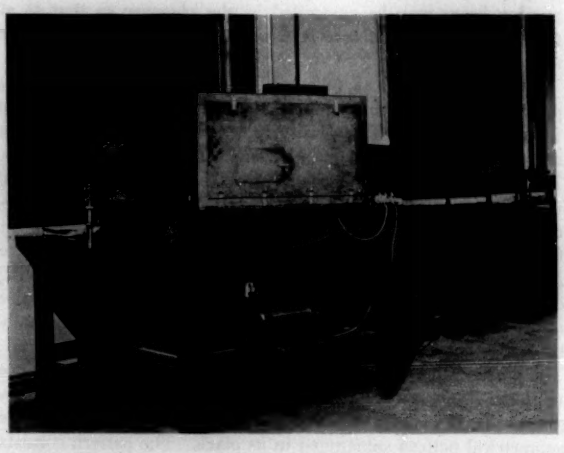


scope is fitted with rotatable nosepiece so that various magnifications may be applied to the object. M_2 is inclinable around a horizontal axis by a screw motion, and may be moved in the direction of the incident beam by means of a rack and pinion. The wedge W is one of the neutral wedges manufactured by the Eastman Kodak Company. The prism P is introduced into a perforation made through the eye-piece and draw-tube and is held accurately in one of the conjugated focal planes of the eye lens by an adjustable clamp, the screen Sc being the other conjugate focal plane. The screen Sc is a magnesium carbonate black whose support is rotatable about a vertical axis, to allow compensation for foreshortening of the image in the mirror. The belt B is a gradu-

ated steel tape, movable by the operator through a crank that actuates the pulley A. The distance separating the mirror M and the observer's eye at E is indicated on the tape by a pointer. All of this various apparatus is inclosed within light-tight and dust-tight housings. A photograph of the projecting system is shown in Fig. 3 and a general view of the complete apparatus in Fig. 4.

Graininess in a photographic deposit is determined by means

FIG. 4.



of this apparatus by comparing the distance to which the mirror M must be driven out so that the magnified image of the photographic deposit seen by the observer appears to be reduced to a fixed degree of uniformity, with that required to reduce an object exhibiting a known inhomogeneity to an identical uniformity.

The field of view consists of a circular patch of two parts, the upper one of which is filled by a magnified image of the deposit under consideration and the lower is illuminated to an equal average brightness by a beam of light from the source S_2. Since the prism which serves as a beam splitting device is placed at the focus of the projecting lens a sharp dividing line is obtained

between the two parts of the field. The screen upon which the image is projected is a block of magnesium carbonate, the surface of which is rendered perfectly smooth by scraping with a steel straight edge. The particles of which this block is composed are so small that the surface appears to be absolutely textureless when viewed by the unaided eye. One-half of the field is therefore entirely free from graininess, and serves as a criterion of complete homogeneity with which the magnified image of the photographic deposit may be compared. The brightness of the comparison beam may be controlled by the observer so that at all times a brightness balance between the two halves of the field may be maintained.

The procedure is as follows: The wedge, W, is moved to a position giving an illumination of the comparison field convenient for good visibility. The density to be measured is placed on the stage and its projected image brought to focus on the screen. The brightness of the image field is then photometrically balanced with respect to that of the comparison field by shifting the condenser C_1. The image, of such enlargement as very perceptibly to show graininess at the more proximate positions of the mirror M, is then made apparently to recede from the observer by driving out the mirror. As it moves away the irregularities noticeable in the projected image of the photographic deposit will gradually bend together and at a certain point they will disappear entirely. The position of the pointer on the tape will indicate the distance from the observer's eye at which this has taken place. The photographic density is then removed and an object exhibiting a definite geometrical pattern substituted in its place. The pattern consists of a commercial cross line screen in which a set of parallel black lines drawn at constant intervals from each other is crossed at right angles by a similar set of lines. The lines are ruled 500 per inch and are of a width equal to that of the intervening clear spaces. The geometrical screen is focused upon the diffusing screen, balanced photometrically with the comparison field, and the distance at which the image is reduced to a fixed uniformity read off, exactly as in the case of the photographic density. A comparison of the two sets of readings will give a comparison of the relative graininess of the two objects, and by a simple mathematical process the irregularity of the deposit may be expressed

in terms of a screen of such a number of lines per inch as would be of equivalent graininess.

Let the necessary factors be designated by the following symbols:

D_1 = the minimum distance at which the magnified image of the standard line screen blends into an appearance of complete homogeneity.

D_2 = the corresponding distance for the magnified image of the deposit under consideration.

M_1 = the magnification used in forming the image of the standard line screen.

M_2 = the magnification used in forming the image of the photographic deposit.

N = the number of lines per inch in the standard line screen.

E = the number of lines per inch in a screen of similar geometrical characteristics, which would be equivalent in graininess to the deposit under consideration.

It is well known that within certain limits the relation between the dimension of an object which is just resolvable by the eye and the distance at which resolution is just possible is linear. That is, the resolving power of the eye may be specified by the magnitude of the angle subtended at the eye by the object considered, this being the case it may be demonstrated that the factors previously defined are related to each other by the following equation:

$$E = N\frac{M_1 D_2}{M_2 D_1}$$

In case $M_1 = M_2$, which is usual in practical work,

$$E = N\frac{D_2}{D_1}$$

The greater the graininess of the deposit the smaller will be the value of E. Graininess is, therefore, inversely proportional to E, or directly proportional to $\frac{1}{E}$, therefore, G

$$G = c \cdot \frac{1}{E}$$

where c is a constant of proportionality.

For the sake of practical convenience it seemed desirable to adjust the value of c so that the values of graininess (G) should be greater than unity. After examination of the data obtained from a number of photographic plates, varying over wide limits

in graininess, it was decided to choose arbitrarily a value of 100,000 for c. This results in values of graininess of convenient magnitude for practical work, the values obtained with the group of plates thus far examined lying between 10 and 200. The numerical specification of graininess, therefore, in terms of the standard line screen, the observed distances D_1 and D_2, and the known magnifications M_1 and M_2, is given by

$$G = 100{,}000 \cdot \frac{M_2 D_1}{N(M_1 D_2)}$$

In making measurements with this apparatus errors may be introduced by the action of causes which determine the objective visibility of the image, by variations in the resolving power of the observer's eye, or by a shifting criterion of the degree of uniformity to which the photographic deposit or the comparison screen is reduced.

The objective visibility of the projected images might be affected by changes in the brightness of these images, due either to variations in the luminosity of the sources following a change in line voltage, or to imperfect photometric balancing of the images of the photographic density and of the line screen, respectively, with the comparison field. Pronounced selectivity in a photographic deposit may occasion difficulty in establishing a correct photometric comparison, but by the introduction of absorption filters in the comparison beam a given color in a photographic deposit may be satisfactorily matched. When making measurements of the line screen with this filter in place another similar filter must, of course, also be introduced into the direct beam. It has been determined that the variation of visibility in the images due either to shifts in line voltage, or to errors in photometric balancing that would ordinarily occur are not of great magnitude.

Another cause that would affect the objective visibility of the image is irregularity in focusing. When using an objective possessing considerable curvature of field, it was found that an average difference of nearly 20 per cent. existed between readings of the half-tone screen taken with the peripheral portion of the field and the central portion of the field respectively, brought accurately to focus on the screen. In order that all readings made in a series of measurements be comparable, it is therefore essential

that a microscopic system giving a perfectly flat field be employed, or if such is not available that the image in every case be carefully focused at some definite zone.

Variation in the readings caused by changes in the resolving power of the observer's eye are also of considerable importance. One factor causing such variation is the changing adaptation level of the eye of the observer. If the measurements be carried out in a darkened room, as they were in the tests reported here, there will be a rapid change in the adaptation level following a transition from daylight to semi-darkness. Experiments showed that these changes were not perceptible in readings of graininess after twenty minutes adaptation from full daylight had been allowed. They also showed that a certain amount of diffuse illumination of a constant low brightness in the room in which the observations were made tended to reduce changes in the adaptation level due to glare, exposure to a certain amount of which is unavoidable. The light sources in the instrument are effectively shaded and the disturbance in the resolving power of the observer's eye incurred by exposure to glare while using the apparatus is so slight as to be negligible. An artificial pupil in the observing eyepiece, *E*, serves to prevent variations in resolving power due to variations in pupil diameter.

On beginning a series of readings, an initial increase in the distance at which the field is reduced to a fixed uniformity will be observable for a very few minutes, after which the values will begin to fall off as a result of fatigue, continuing to do so until the test is at an end. Since readings on the density being examined and the standard line screen are made alternately, progressive variations in the distance at which complete homogeneity occurs have no effect on the absolute value of the graininess computed from such readings. Supposing perfect adaptation, the rapidity of change in the practice curve will be dependent upon the number of readings taken per unit of time. It was found convenient to take readings at intervals of about twenty seconds. There will, of course, be erratic variations in the practice curve which cannot be associated with any definite physiological or psychological cause.

Since, in the apparatus described, one sensation is compared with another by a threshold method, the readings will be liable to the errors usual in all threshold measurements. It is usual to minimize this error by increasing the number of readings. If in the

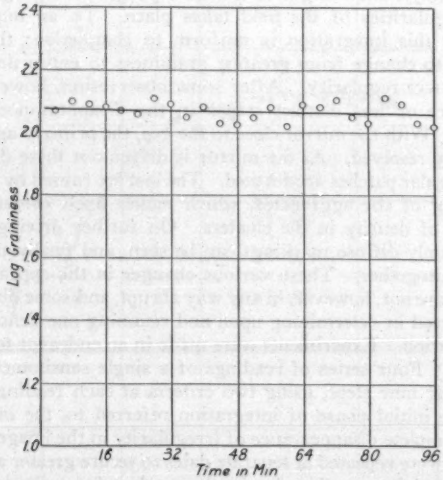
present case, however, too great a number of readings be taken, other errors will be introduced due to the constantly shifting form of the practice curve. It was determined by experiment that five consecutive readings on the photographic negative, followed by five readings of the screen, gave an accuracy equal to that attained if ten or twenty readings were taken. If a closer approximation is desired the negative and screen are reread.

All the various disparities in the readings of graininess on a given density, be they due either to changes in the resolving power of the eye of a given observer, or to the individual peculiarities of different observers, are compensated for in the reduction of the readings by the fact that readings of graininess in the density measured are compared with readings of the graininess of a screen of known irregularity and of identical brightness, the two sets of measurements being separated by an interval of such brevity as to preclude marked changes in the form of the practice curve. The effect of regular changes in the form of the practice curve is compensated by a method of interpolation. The effect of irregular changes is dependent upon the rapidity and magnitude of these changes and cannot be eliminated: such changes must, therefore, be reduced as far as is possible. To this end it is essential that all exposure of the observer's eye to glare be avoided, and that the readings be taken in regular sequence and with as little interruption as possible. It is thought that by the observance of these precautions the influence of the variable factors has been so reduced as to bring the accuracy of the method well within the limits usual in sensitometric work.

In order to illustrate the general shape of the practice curve and to determine the precision with which a given graininess value can be established, the data in Table I are presented. A photographic deposit of relatively high graininess was placed in the instrument and the observer after a few minutes of an initial adaptation began a series of readings which continued for approximately one and one-half hours. Five settings of distance were made on the density being examined at intervals of approximately twenty seconds. The line screen was then inserted and another set of five readings made, the average of these two groups of five readings give a determination of D_2 and D_1 respectively. This was continued throughout the period of the test, twenty-four such determinations of both D_1 and D_2 being made in that interval

of time. These values are shown in column D_2 and D_1 of Table I. In column E are given the computed values of that factor as previously defined, the graininess values being entered in column G. In plotting graininess-density curves, it is found more convenient in practice to plot values of the logarithm of graininess rather than the graininess values themselves. These values are shown in the column thus designated. In the column marked ΔG are the deviations of the individual values from the mean of the entire

FIG. 5.



set. At the bottom of the table is shown the mean deviation from the mean, this being 6.5 per cent. From very careful analysis of a large number of results, it is estimated that the values of graininess obtained by this method are subject to a probably error of ±5 per cent. In Fig. 5 the values of log graininess are plotted against the time in minutes from the starting of the series of observation. It will be noted that the first six values lie very close to the straight line, and that as the time increases the scattering of the determinations from its mean becomes more pro-

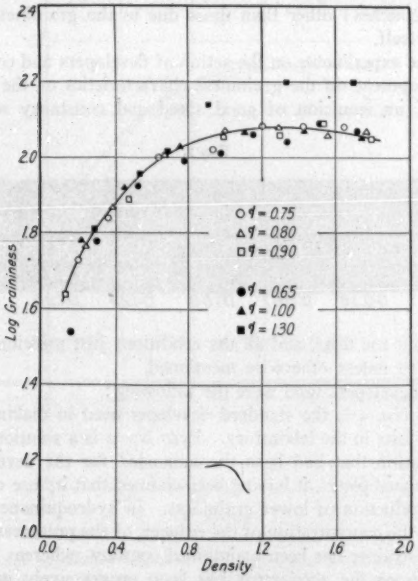
nounced. This undoubtedly is due to fatigue. However, it will be noted that the curve drawn through the points is practically parallel to the X axis, thus showing there is no tendency to drift either up or down in the determination of the graininess values. In practice such a schedule of procedure is adopted that fatigue effects evident in this particular case are eliminated.

In making readings of graininess it is important to choose a criterion that will be adhered to for all observations. As the image of the plate projected on the screen apparently recedes from the eye, what might be termed a progressive integration of the irregularities of the field takes place. To an unpracticed observer this integration is uniform to completion; the image appears to change from greatest graininess to entire uniformity with perfect regularity. After some observation, however, several more or less distinct stages in the disappearance become evident. With the mirror close to the eye, the primary aggregates are easily resolved. As the mirror is driven out these disappear, and irregular patches are formed. The last are caused by a certain clustering of the aggregates, which makes itself evident by an increase of density in the clusters. On further driving out the mirror, only diffuse markings can be seen, and finally these disappear altogether. These various changes in the appearance of the field are not, however, in any way abrupt, and some difficulty is encountered in determining upon and retaining one definite stage as a criterion. Experiments were made in an endeavor to achieve this end. Four series of readings of a single sensitometric strip containing nine steps, using two criteria at each reading, one of these the initial phase of integration referred to, the other that of the complete disappearance of irregularity in the image. These readings were repeated at separate dates to secure greater accuracy, a total of eighty readings having been taken for each step of the sensitometric strip. It was found by a comparison of these readings that those taken using as a criterion the point marking the first step in the fusing of the image of the photographic deposit, the change from aggregates to clumps, show much greater correspondence with each other than those taken at the disappearance threshold, hence this point was adopted as a criterion for all subsequent readings. The value of a series of readings in an investigation will depend on the accuracy with which this criterion is held from day to day. Fig. 6 shows readings taken on sensito-

metric strips made from the same material (not, however, on the identical strips), the two sets of readings having been separated by an interval of three months.

In the figure referred to, the symbols in full black are those of the first set of readings, and the outline symbols those of the second. They indicate the order of accuracy with which the

FIG. 6.



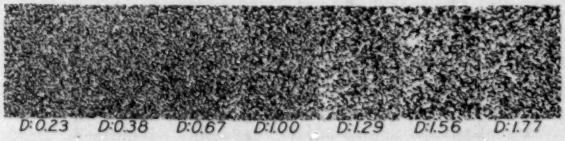
criterion chosen for this work may be held, and also give an idea of the amount of scatter that occurs in the readings. It may be remarked that the readings of the third strip of the first series appear to indicate an increase of graininess in the higher densities, due to the relatively high gamma, 1.30, to which that particular strip was developed, rather than to normal scatter.

In comparing the performance of various emulsions in respect

to graininess, the strips were exposed in a non-intermittent sensitometer of a type recently described [5] and developed in the developer listed as Pyro No. 1 in the accompanying table, at a temperature of 20° C., fixed in plain hypo, and washed and dried under as constant conditions as could be commanded. In preparing the sensitometric strips to be measured for graininess exceptional care must be exercised to avoid any irregularities in the texture of the gelatine film (such as dust particles or microscopic scratches) other than those due to the graininess of the coating itself.

In the experiments on the action of developers and conditions of development on the graininess characteristics of the finished negative, an emulsion of good speed and constancy was used

FIG. 7.



throughout the tests, and all the conditions just mentioned were adhered to unless otherwise mentioned.

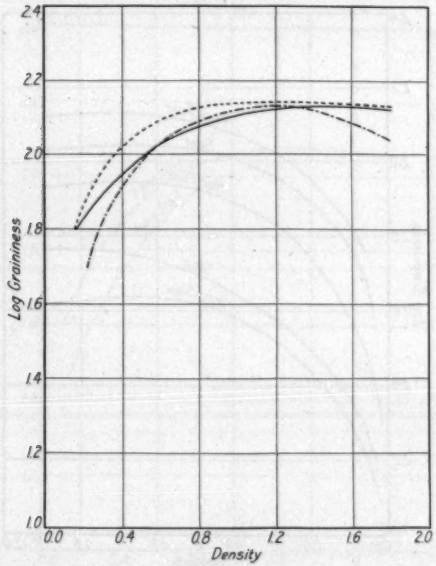
The developers used were the following:

Pyro No. 1 is the standard developer used in making sensitometric tests in the laboratory. Pyro No. 2 is a solution of low concentration that had been recommended for the development of high-speed plates, it having been claimed that its use conduces to the production of lower graininess. In hydroquinone Nos. 1, 2, and 3, the concentration of the reducer, of the preservative, and of the restrainer has been maintained constant, whereas the concentration of the accelerator has been progressively increased. Hydroquinone No. 4 is an extensively used process developer. The ferrous oxalate and amidol developers were selected as typical inorganic and organic developers working without alkali. The paraphenylene-diamine developer is one recommended by M. M. A. and L. Lumiere and A. Seyewetz [2] for securing fine grain. These investigators have pointed out that this reducing agent when used without sodium sulphite apparently develops the latent image

through a process very analogous to physical development. For the information of those interested the complete developer formulæ are given following the discussion and the results.

The graininess-density curve represented in Fig. 6, already alluded to, was obtained from a high-speed plate developed in the

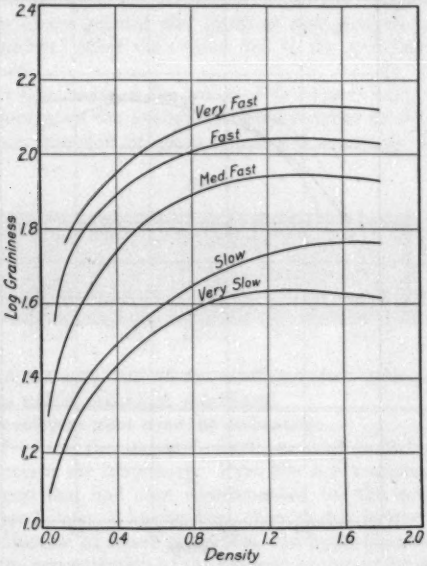
FIG. 8.



Pyro No. 1 developer listed in the accompanying table. It shows that within the range of contrast (gamma) represented, the graininess-density curves of the various strips show no appreciable mean variation, save in the case of the strip which has been developed to a gamma of 1.30. Graininess undoubtedly varies with gamma in the case of very low or very high gammas, but the relation of gamma to the graininess-density curve has not as yet been fully investigated. The correspondence of the graini-

ness-density curve to what is seen in the negative by the observer is illustrated in Fig. 7, in which prints from negatives given equivalent exposures at the plane normally occupied by the diffusing screen in the graininess apparatus have been printed to approximately uniform densities and arranged in the same order

FIG. 9.



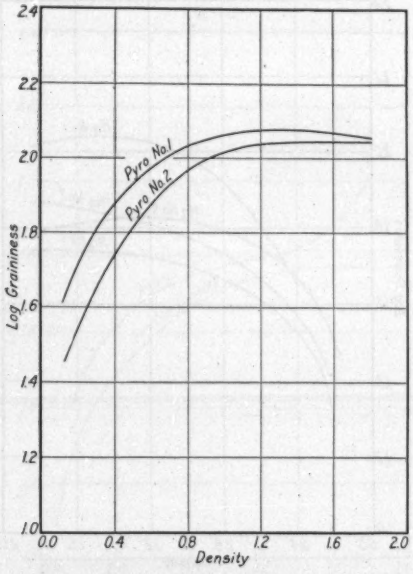
as the steps of the sensitometric strip from which they were taken. The sensitometric strip from which these photomicrographs were made is one of those of which Fig. 6 represents the curve. It therefore affords a direct comparison between the graininess-density curve and the appearance of graininess in the strip.

The shape of the graininess-density curve is constant for a given batch of emulsion, and approximately so for distinct batches of a given emulsion, but shows striking differences in emulsions

of different preparation. Fig. 7 shows the curves obtained by the measurement of three very fast emulsions of different manufacture. Curves obtained from readings taken on a series of plates of one brand, but of different sensitiveness, are shown in Fig. 9.

A comparison of the performance of the two pyro developers

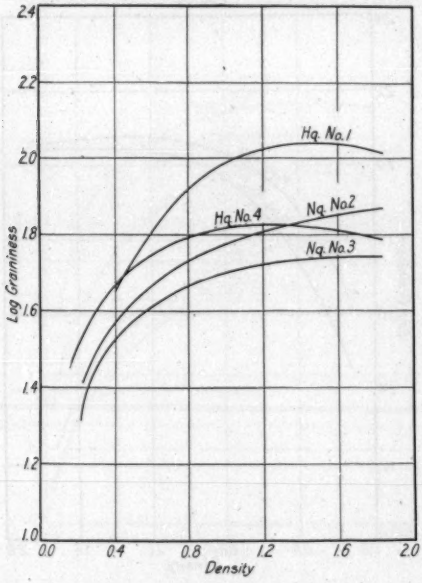
FIG. 10.



listed, in respect to graininess is given in Fig. 10. The effect of modifying the alkalinity of a hydroquinone developer is shown in Fig. 11. Fig. 12 represents the curves obtained with the two alkali-free developers. Fig. 13 shows curves obtained from strips developed by means of the paraphenylene-diamine developer listed, to gammas of 0.25, 0.40 and 0.50. For comparison, curves obtained from strips developed by Pyro No. 1 to gammas of 0.25 and 1.00 are given.

A test was made of the effect of increasing the concentration of restrainer in the developing solution. Potassium bromide was added to successive portions of Pyro No. 1 developer in quantities such that the concentration of bromide in each succeeding portion would be twice that of the preceding, the concentration of

FIG. 11.



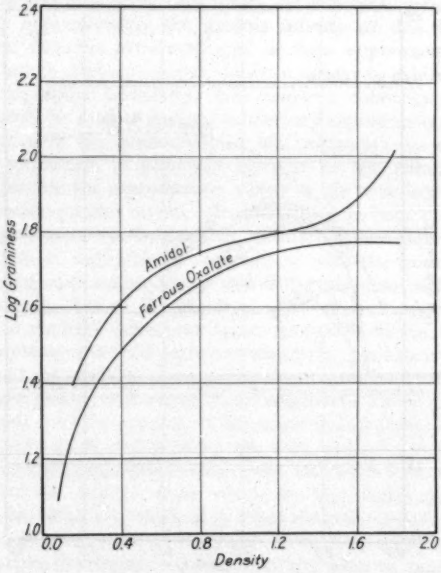
bromide in the series of baths thus increasing logarithmically. Careful measurements failed to show any appreciable effect on the graininess of the strips which had been developed in concentrations of bromide far beyond those which would be used in practical work.

To determine if the temperature of the developing solution has a bearing on graininess, sensitometric strips were developed

in Pyro No. 1 at temperature of 15°, 20°, 25°, and 30° C. No variation in the graininess-density curve was noticed.

It has been thought that an "incipient reticulation" produced in the gelatine film when using an alkaline developer and an acid-fixing bath, especially at higher temperatures, might promote graininess. Strips developed in Pyro No. 1 and also in hydro-

FIG. 12.

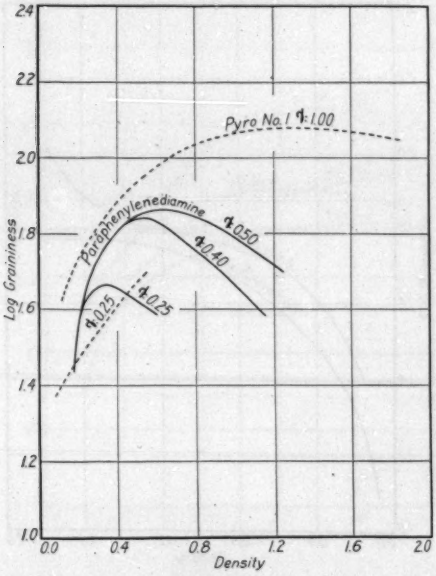


quinone No. 4 developers and fixed in a hypo solution containing no addition, and also in a hypo solution containing acetic acid and potassium alum hardeners, showed no difference in graininess. These tests were carried out at a temperature of 20° C.

An inspection of Fig. 9 will show that the claim that Pyro No. 2 produces lower graininess than other pyro developers is in this case substantiated. In Fig. 10 it will be noticed that an

increase in the concentration of carbonate up to the point of saturation, in the hydroquinone developer used, is in each case followed by a pronounced falling off in graininess. It is also an interesting fact that, though the caustic hydroquinone developer (Hq. No. 4) appears to have a very much more powerful disintegrating action on the gelatine coating of the plate, and

FIG. 13.



though it develops very much faster than Hq. No. 3 developer, it shows considerably higher graininess than the latter developer.

In the case of the paraphenylene-diamine developer (Fig. 12) it will be observed that the successive curves secured from increasing gammas overlap each other in the lower densities. This is not the case with other developers thus far investigated, the deviation from the normal curve, obtained with very low gammas,

being approximately parallel to the normal curve secured with full development. The dotted curves in Fig. 12 represent the deviation from the normal in the case of development with Pyro No. 1. Another notable characteristic of this paraphenylenediamine developer is the remarkable manner in which the graininess falls off in the higher densities. Unfortunately, this developer calls for about six times the normal exposure in the plate, moreover the contrasts obtained with it are not high, a gamma of 0.67 being obtained with 1.75 hours development, which figure represents approximately the gamma infinity of this developer when used with the plate employed in these experiments. The deposit, though slightly colored, does not appear to exhibit noticeably photographic selectivity, and hence a contrasty printing medium must be used to secure satisfactory reproductions.

Except with the spectroscopist, who examines his negatives directly, graininess is generally brought to the notice of the photographer in the reproduction, either in direct enlargement or on the motion-picture screen. It is assumed in both these cases that the graininess of the printing medium, either paper or cine positive film is negligible in comparison with the graininess of the negative, and consequently that the graininess of the print is substantially that of the negative. Graininess is usually most apparent in the high lights and lighter half-tones of the reproduction. Anything that will tend to reduce the graininess in those densities of the negative from which these portions of the reproduction are prints, will result in an effectively lower graininess in the result. As the gamma of the negative increases, its higher densities tend more and more to take their position on the upper portions of the graininess-density curve, and since it is the higher densities of the negative from which the high lights and lighter tones of the print are taken, it is these densities which virtually determine the graininess of the print. This may explain the fact that negatives developed to a high contrast seem to exhibit more grain than negatives developed to a low contrast, although measurements show that the graininess-density curves would in the two cases fall on the type curve, a condition that would be filled through a very wide range of gamma. The same fact may also explain why warm developing solutions are thought to produce grainier negatives. More chemical fog may develop up under these conditions, and hence to attain a given gamma the plate

must be developed to a higher average density. From a practical standpoint such a negative would be called grainier than a normal negative, because the general increase in density of the negative had brought with it a corresponding general increase in graininess.

Previous investigations have shown that the size of the silver grain is almost independent of the composition of the reducer. The curves that accompany this article show, however, that there is a very appreciable difference in the graininess produced by different developing agents. Graininess then is not altogether a function of grain size, which again emphasizes the distinction between grain and graininess. These results also show that rapidity of development does not necessarily conduce to low graininess. Development goes on faster at higher temperatures without reduction in graininess. An extreme case is presented by paraphenylene-diamine in solution with sodium sulphite alone, which acts very slowly and produces low graininess. An addition of an alkali increases the developing action of this developer enormously, but at the same time increases graininess. The explanation in this case is that the character of development has been changed, presumably from a type of physical development to a typical chemical development. But in chemical development itself, though increasing the concentration of alkali may be said generally to increase the speed of development and at the same time to cause a decrease in graininess, in this case also the graininess does not appear to be a function of the speed of development, but rather of some property intimately related with the specific alkali employed.

DEVELOPER FORMULÆ.

Name	*R*	*A*	*S*	*B*	
1. Pyro No. 1	10.0	37.5	32.0	0.5	Sodium bisulphite −8.7
2. Pyro No. 2	20.0	25.0	35.0	0.35	Sodium bisulphite −3.0
3. H Q No. 1	5.0	20.0	75.0	1.0	
4. H Q No. 2	5.0	80.0	75.0	1.0	
5. H Q No. 3	5.0	200.0	75.0	1.0	
6. H Q No. 4	12.5	25.0 (NaOH)	0.0	12.5	Sodium bisulphite −25.0
7. Amidol	8.0	0.0	24.0	0.18	
8. Paraphenylenediamine	10.0	0.0	60.0		

The developing formulæ are written in accordance with the system proposed by C. E. K. Mees,[6] the values being grams of the substances indicated per 1000 c.c. of developing solution.

TABLE I.

	D_2	D_1	E	G	Log G	ΔG
1	96	56	857	117	2.068	− 2
2	91	56	795	126	.100	+ 7
3	93	58	802	125	.097	+ 6
4	90	55	827	121	.083	+ 2
5	86	51	843	119	.076	0
6	90	52	863	116	.064	− 3
7	86	57	770	130	.114	+11
8	86	53	810	124	.093	+ 5
9	87	47	904	111	.045	− 8
10	85	52	820	122	.086	+ 3
11	80	43	925	108	.033	−11
12	86	46	934	107	.029	−12
13	83	47	883	113	.053	− 6
14	89	52	820	122	.086	+ 3
15	80	47	945	106	.025	−13
16	83	50	800	125	.097	+ 6
17	81	51	814	123	.090	+ 4
18	83	59	700	143	.155	+24
19	80	47	880	114	.060	− 5
20	80	43	930	108	.033	−11
21	72	51	764	131	.117	+12
22	72	45	800	125	.097	+16
23	74	41	930	108	.033	−11
24	71	36	960	104	.017	−15
Mean	..	..	...	119	.....	7.7
				Mean G (per cent.)		6.5

DEVELOPER NO. 9. FERROUS OXALATE.

Solution A.

Potassium oxalate	22 gm.
Water	1000 c.c.

Solution B.

Ferrous sulphate	270 gm.
Sulphuric acid	10 c.c.
Water	1000 c.c.

REFERENCES.

[1] EDER'S *Jahrbuch*, 1903, 193.
[2] *Bulletin Societe Française*, 1904, xx, 297 and 422.
[3] *Astrophysical Journal*, 1904, xx, 113.
[4] CALLIER: *Phot. Jour.*, 1909, p. 200.
[5] JOURNAL OF THE FRANKLIN INSTITUTE, 1920, vol. 189, p. 303.
[6] MEES, C. E. K.: *British Journal of Photography*, 1917, p. 535.

EASTMAN KODAK COMPANY,
ROCHESTER, N. Y.,
July, 1920.

Application of Photography to Transcription of Original Records.—ARTHUR WORISCHEK of the General Electric Company presents in the *Jour. Ind. Eng. Chem.* (1920, vii, 679) a discussion of the use and methods of photography for making copies of articles in books and periodicals not directly accessible to the research worker. No argument is needed to convince any one of the superiority of such methods to the most careful copying, and it is astonishing that they have not had much wider application than has so far been shown. The question was discussed some years ago in this journal (JOURNAL OF THE FRANKLIN INSTITUTE, 1901, clii, 351; 1914, clxxviii, 743) in which the advantages of the methods were shown, and some practical problems treated. It was there pointed out that the permanence of the paper and of the impression must be carefully considered. The ordinary blueprint has been found to be very durable, but even better is the so-called gum-dichromate method, using a good carbon pigment. In the latter of the above quoted articles, a method of copying without the use of the camera was indicated, being the employing of glass plates coated with luminous paint. When the sheet from which the copy is to be made is written or printed only on one side, this plan is generally applicable and gives good results.

Worischek gives illustrations of several of the newer forms of apparatus for copying purposes, and also mentions an interesting and useful recent application of the film-camera; namely, recording the reading of meters, the camera being operated somewhat on the principle of the motion-picture machine.

H. L.

Fire-damp in the Alsatian Potassium Mines. (*Le Génie Civil*, July 31, 1920.)—In view of our continuing state of war with Germany the great deposits of potassium salts in the eastern part of France are of much interest. One phase of the operation of these mines is the development of fire-damp. At the Theodore mine an explosion due to this cause resulted in the death of eleven workmen. In Alsace the gas is localized in layers of bituminous schist deposited with the strata of potassium salts. A peculiar smell pervades the mines recalling fish oil and also hot mineral oil. Hydrogen sulphide is likewise present as well as a little hydrogen.

Since the normal quantity of dangerous gas is small, the method of working employed by the Germans permitted the use of lamps with open flame except in certain specified conditions. After the French had taken over the operation a pillar was blown up and the roof collapsed. Much fire-damp was set free and an explosion followed with disastrous results. To avoid the recurrence of similar accidents the French Bureau of Mines has prescribed the employment of safety lamps in all the workings. Better ventilation will be provided and a more secure method of supporting the roof will be introduced.

G. F. S.

THE CROSS-ARM WIND-BALANCE.*

BY

DR. A. F. ZAHM.

Bureau of Construction and Repair, U. S. N.

Preface.—When, during the early months of 1918, the new 4′ x 4′ wind-tunnel, at the Washington Navy Yard, was nearing completion, an aerodynamic balance was needed for it that could measure lift, drag and pitching moment, and could be delivered at an early date. The only balance immediately available in America then was one that had recently been made for sale by Mr. C. B. Kirkham, Chief Motor Engineer of the Curtiss Aeroplane and Motor Corporation, from patterns made by that company for its 4′ x 4′ tunnel. The balance had been devised for that company, in 1916, by the present writer, then Chief Research Engineer, and is an adaptation of his former balance used early in 1902. It was reduced to scale drawings by his assistant in the company, Mr. A. P. Thurston, who supervised its construction and made the calibration.

Construction of the Balance.—Fig. 1 shows the external appearance of the instrument as it was assembled, just after delivery, and mounted on the under side of a plank representing the floor of a wind-tunnel.

The balance consists primarily of a hollow vertical main shaft capable of rotating about its own axis and about two coördinate horizontal axes, one normal, the other parallel to the wind direction. This sturdy main shaft is supported in a bronze hub having four split spokes, accurately milled, into which are bolted four steel-weighing beams provided under their tips with knife-edges resting in V blocks, which themselves rest in the bottoms of four iron lugs jutting down from the base casting screwed to the under side of the tunnel. One pair of the V blocks can be raised to carry the whole vibrating system, or lowered to let it rest on the other pair. Thus the main shaft can vibrate either across or along stream, and thereby measure lift or drag on the wind model.

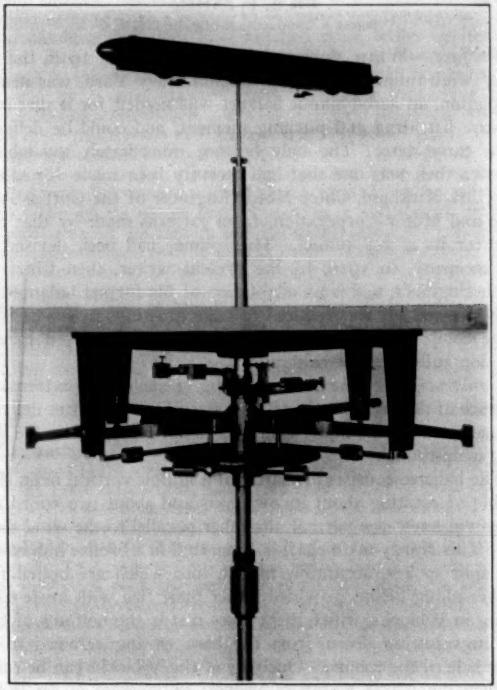
A ratchet arm fixed to the main shaft turns it through any

* Communicated by the Author.

desired angle and clamps it to the hub's large flange, having 360 teeth, accurately milled and numbered.

Rotating in ball-bearings in the upper half of the main shaft,

FIG. 1.



The cross-arm wind-balance supporting a model.

is a light model-holding spindle whose lower end has a horizontal arm engaging the forked vertical arm of a small bell-crank balance, for weighing the wind moment about the spindle axis.

In the upper left corner of the photograph is shown a fourth

weighing beam for vertical forces, but which can be ignored for the present, not yet having been put to use.

Suitable tares are provided for balancing the three weighing beams, and for adjusting their sensibility; also for bringing the centre of gravity of the main shaft and all it carries, including the model, precisely into the vertical axis of rotation, and to a suitable height in the axis. Oil dampers, not shown in the photograph, are added to the ends of the weighing beams, to steady them when necessary.

To ensure that no air shall leak through the tunnel floor where the main shaft enters, this carries an inverted cup dipping into an annular cistern of oil in the hub of the base casting. This casting, which supports the entire balance, is fixed to the underside of the tunnel floor with four supporting screws fitted neatly in elongated slots, so as to admit of orientational adjustment relatively to the wind direction.

A telescopic wind-shield, not shown in the photograph, encases the spindle from the tunnel floor up to within a few inches of the model.

The whole balance and moving weights aggregate about 60 pounds.

Assembly and Adjustment.—While assembling the balance, care is taken to see that the three truss rods joining the ends of the balance arms, and not shown in the photograph, are of such length that the two knife-edge systems are mutually perpendicular. No truss rod spans the weigher's angle between the two graduated beams. Then the instrument is mounted under the tunnel, and its tares are adjusted to ensure equilibrium with the main shaft vertical, whatever its orientation; and the scales for showing deflections are adjusted to read zero for that position. The base casting is next given such orientation that the wind drag on the exposed main shaft, or a drill rod chucked in it, is parallel to the lift knife-edges, and shows no horizontal lift component. This can be done truly to less than .05°. Then a long thread attached to the axis of the spindle is stretched parallel to the tunnel walls to see whether it exerts any lift component. In the present installation the zero lift direction for the thread is parallel to the tunnel axis to less than .05°.

The distance of the top of the main shaft above either knife-edge system, whatever be the sag of the cross-arms, due to the

nearly 60 pounds weight of the balance, is found by measuring the moment about the knife-edge pair produced by a thread attached to the top of the shaft, and exerting a known force horizontally across the knife-edge direction. The top of the shaft then can be used as a bench mark to find the height of a model above the knife edges. The top of the base casting also can be used as a bench mark, its distance from the knife-edge seats having been measured before the final mounting, by calipering from the top of the casting to a straight edge resting in the V blocks. The distance from the model to either bench mark can be directly measured, and thus the distance from the model to either knife-edge axis can be determined truly to about 0.1 per cent. The knife-edges are about one yard below the axis of the 4′ x 4′ tunnel.

Graduations and Sensitivity.—The main weighing beams have each two sliding weights, a large and a small one, playing over their respective scales ten inches long, graduated to inches and tenths. The smaller weight has one-tenth the mass of the larger, and measures .001 pound-inch moment when read to one-tenth of its smallest division. By using a lighter weight, and adjusting for fine sensitivity, the balance can be made to indicate an increment of static moment less than .0001 pound-inch, which represents a drag of .000003 lb. applied to the spindle at the axis of the tunnel. This is hardly one per cent. of the smallest measurement the balance is usually required to make.

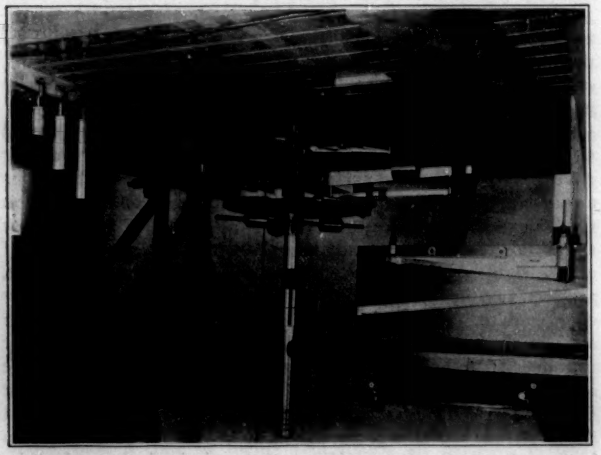
The single beam for weighing moments about the vertical axis also is graduated in inches and tenths, and carries two sliding weights, the lesser of which measures to .001 pound-inch when the scale is read to one-tenth of a small division.

Original Form.—In the form of balance used by the writer in 1902, in his wind-tunnel, the main shaft could rock along and across stream simultaneously, so that lift and drag could be measured at one time. This was effected by a kind of gimbal support. One pair of cross-arms rested at their tips in knife-edge seats borne by a horizontal ring, which itself rocked about a pair of knife-edge seats square with the other two, and borne by a round base plate mounted on the tunnel. This base plate was circularly graduated and could rotate in a horizontal plane, so as to make the resultant air force on the model perpendicular to the direction of one pair of knife-edges. Since in many cases the air force is horizontal and at a known height, it could thus be

directly determined in magnitude and orientation. Or, if preferred, the knife-edges could be set respectively along and across current, so as to measure the rectangular components of the force, *i.e.*, the lift and drag.

This was probably the earliest of the now familiar bell-crank aerodynamic balances. Structural drawings of it were furnished to the British Government early in 1905, and a written description of its simplest form had been communicated to the

FIG. 2.



The cross-arm wind-balance attached underneath the wind-tunnel floor.

Pittsburgh meeting of the American Association for the Advancement of Science, June 30, 1902, in the following words:

"Among other instruments that we are using may be mentioned a universal pressure balance. This consists of a bell crank mounted on knife edges above the tunnel, one arm of which, the horizontal, is graduated and provided with weights, while the other arm runs vertically down into the tunnel, and holds the object whose resistance is to be found. The knife edges may be set crosswise the tunnel, or lengthwise, or at any

angle. Thus by simply turning the balance, it may be used to measure the lift, drift, or the resultant pressure on the exposed body at any angle whatever. The instrument is graduated to tenths of a gramme, and is strong enough to measure several thousand grammes."

Experience with the Present Balance.—In its present form the cross-arm balance has proved satisfactory in point of permanency of adjustment and precision of measurement. The mounting directly underneath the floor of the tunnel is practicable when the latter is made of seasoned wood and is reasonably free from jarring. The cast-iron base could be made to rotate in a horizontal ring, if desired, but little want for this has been felt. If more were required than the measurement of forces and moments, other attachments could be added which are too well known to need description here.

Accompanying Equipment.—Fig. 2 shows the balance screwed to the under side of the 4′ x 4′ wind-tunnel, and in its working environment. The air current in the tunnel is maintained by a four-blade suction screw chain-driven from an electric motor on the floor of the laboratory. The speed of the motor, and hence of the air flow, can be held steady by a sliding rheostat under the shelf on the right of the balance. Above this shelf, or writing table, are seen two inclined alcohol manometers. One is permanently connected to a fine hole in the side of the tunnel, and, after calibration, is used to indicate the speed of the air; the other is connected to a standard Pitot tube, temporarily placed at the axis of the tunnel, to calibrate the permanent speed indicator just described. With this equipment a single observer can hold the airstream constant at any speed up to more than 60 miles an hour, and make accurate readings of the wind velocity and of the component forces and moment of the wind on the aerodynamic model.

U. S. ARMY SEARCHLIGHTS.*†

BY

CHESTER LICHTENBERG.

Captain of Engineers, U. S. Army. Member of the Institute.

FINDERS.

44. The range of searchlights depends in a great measure upon the relative size of the target which is being sought. It has been found that if the target can be magnified in any way the range of the searchlight can be increased. This has led to investigations and developments of certain searchlight target finders. The devices are essentially telescopes, but so proportioned as to be particularly suitable for night work and for distant targets which are relatively small in size and which present but small contrast against their background. Searchlight target finders must, of necessity, be of the Galilean type. Prisms intercept too much of the light energy and therefore have been excluded. It is believed that these target finders will be most suitable if they have a magnifying power of from four to five times and a field of 9 degrees or greater.

OBSERVER'S POSITION.

45. The relative positions of searchlight, target and observer are of extreme importance in the rapid detection of a target. It has been found that, particularly with high-intensity arc searchlights, there is a minimum distance that the observer can be near the searchlight and see a target. This is due to the fact that these types of searchlights, particularly when equipped with front doors, have a cone of highly illuminated air particles in their immediate neighborhood. This cone obscures the vision of an observer close to them, so much so that he can scarcely see more than a few hundred yards in the direction of the beam. Experiments made with a high-intensity searchlight and with the observers set out on a base line parallel with the searchlight trunnions gave very interesting results. An airplane was used as a target. It flew through the beam at elevations of 3000 feet to 5000 feet and at ranges of two to four miles. The percentage of times that it could be seen by each of the observers along the

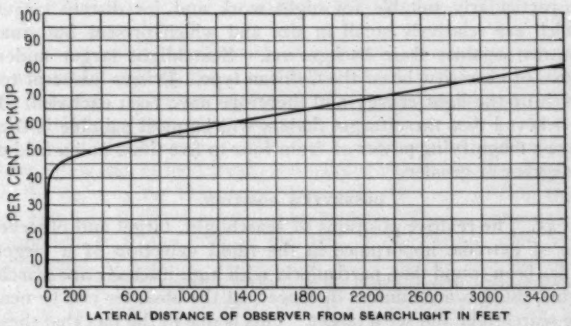
* Communicated by the Author.

† Concluded from page 542, Vol. 190, October, 1920.

base line was recorded on a number of successive nights. The results are shown in the graph in Fig. 34.

46. In addition to choosing proper location for an observer, it is necessary to suitably shield the observer from stray light. It has been found that the pupil of the eye is very sensitive, particularly at low illuminations. It has been found necessary, therefore, for accurate searchlight determinations to exclude from the observer's eye all light excepting that which returns to him from the target and such light as he cannot avoid receiving from the sky. This is done by providing observers with hoods similar to those provided with the old-time stereoscopes. In place of the

FIG. 34.



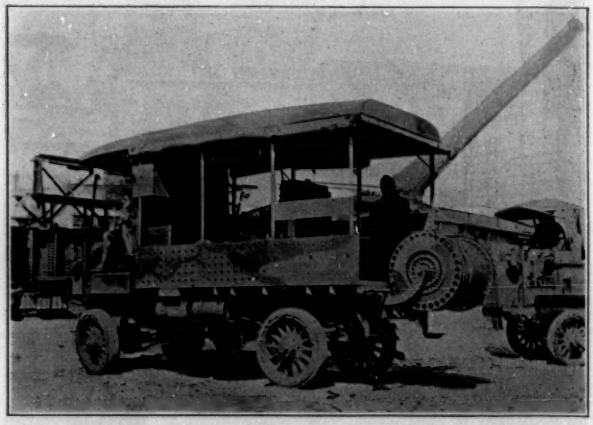
Graph illustrating relative ability of observers stationed in line with the trunnions of a searchlight to pick up airplanes in the beam of the searchlight.

lenses, tubes about one inch in diameter and about fourteen inches long are provided. The hoods have the face portion trimmed with black velvet so as to make close contact between the face of the observer and the edge of the hood and thus exclude all extraneous light. The entire equipment does not weigh over one pound and is strapped to the head of an observer by an elastic band. He is thus permitted to gaze along the searchlight beam and in the direction of it, and his vision is restricted to within two or three times the width of the searchlight beam. This scheme has been tried with eminent success and has proven unusually adaptable for field service.

POWER UNITS.

47. Mobile searchlight power units have been the subject of a great deal of study. The entrance of the United States into the war found the Army equipped with only a few mobile power units. Eight of these consisted of 15-kw., 125-volt, direct-current, gasoline-electric sets, each mounted on a 3½-ton F. W. D. truck. One of these sets is shown in Fig. 35. It is relatively mobile, but difficulty was found in driving it through heavy sand and through certain bad roads. It proved, however,

Fig. 35.



Fifteen kilowatts, 125 volt gasoline-electric generating set, mounted on 3½ ton gasoline driven truck and illustrating an early design of mobile power plant.

to be the most useful power plant of its kind. Nevertheless, there was one objection to it. It required an extra lorry to carry it around and thus meant twice as much equipment as though the engine for driving the lorry was used for driving the electric generator. Another mobile power unit is shown in Fig. 4. It was an attempt to place stationary gasoline-electric generating sets in service with the mobile forces. One of the standard 125-volt 25-kw. sets used for coast-defense fortifications was placed on a standard 3½-ton trailer. The unit was mobile but only relatively so. It could be moved easily over hard roads,

but only with difficulty over bad roads. It could not be moved at a speed to exceed about five miles per hour. Besides, it had to be propped into place when the generating set was operative.

FIG. 36.

Five kilowatt gasoline-electric generating set, mounted on artillery limber and intended for being drawn by horses or mules.

The result was a rather unwieldy equipment which did not prove successful under field conditions.

48. Still another type of portable searchlight power unit is

shown in Fig. 36. It consists of a 5-kw., 60-volt, direct-current generator, direct connected to a Winton four-cylinder gas engine, the combination being mounted on a standard artillery limber. This unit formed one-half of a searchlight equipment, the other half being shown in Fig. 48. It proved successful within certain narrow limits, but on account of being horse-drawn and also on account of its relatively small capacity, it did not prove successful under field service conditions.

Fig. 37.

1917 design of mobile searchlight power unit, typifying the equipment first furnished to the American Expeditionary Forces in France.

49. The early specifications received from the A. E. F. indicated the need for a mobile searchlight power unit of relatively simple design, having at the same time sufficient cargo capacity, in the form of a lorry body, to permit carrying the searchlight and auxiliaries on the same chassis. The first attempt at meeting these specifications is shown in Figs. 37 and 38. These illustrate a standard Engineer Department 5½-ton Mack cargo truck with a 15-kw., 125-volt, direct-current generator, placed on an extension of the engine crank shaft. The cargo body is provided with a cable reel and a 36-inch high-intensity arc, drum-type

searchlight on a wheeled mount. Underneath the cargo body is located a series rheostat for adjusting the current to the searchlight, and a switchboard for regulating the generator. One hundred and eighty of these units were built. Thirty of them were in service with the First and Second Field Armies, A. E. F., in France at the time the November 11, 1918, armistice was signed. A quantity of them were in transit, and the balance were ready

FIG. 38.

1917 design of mobile searchlight power unit, showing generator, engine, switchboard, cable reel and 36-inch, 150 ampere, high intensity arc, wheeled barrel searchlight.

for shipment when water transportation cargo space should be made available. These units proved relatively successful on hard roads or on dirt roads with sufficient bottom to withstand their weight. They had a maximum speed of twelve miles per hour. They could carry the entire equipment of one searchlight section. They were self-contained, and, in so far as their design limits permitted, exceptionally well performed the functions of a searchlight power unit.

50. Early experience with the 5½-ton searchlight power unit

previously described showed that it was not quite mobile enough for certain field army conditions. Speed was a necessity. Relative lightness was essential. Besides, the development of the open-type searchlight reduced the weight of this portion of the equipment by over 50 per cent. The result was the possibility of using some form of standard motor car or light motor truck with suitable body. The first attempt to meet this condition is shown in Fig. 39. Here a standard 145-inch wheel base Cadillac chassis

Fig. 39.

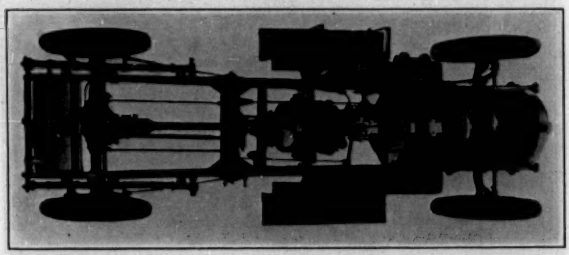
1918 design of mobile searchlight power unit, showing switchboard, cable and 60-inch, 200 ampere, medium intensity arc, open type searchlight.

and engine were equipped with a generator located on the propeller shaft and with a special body for carrying the searchlight and crew. The generator location is shown in Fig. 40. The armature has a hollow shaft. The propeller shaft is run through this. The generator armature is coupled to the propeller shaft by means of a clutch. This is so arranged that the propeller shaft may be connected either to the generator or to the differential and thus the engine used to drive either the generator or the traction wheels. This form of unit reduced the total weight of the power unit and lorry from 14,000 pounds to 6000 pounds. The design was so happily selected that spare parts for it were

readily obtainable at all Motor Transport Depots of the A. E. F., since Cadillac touring cars had been standardized for certain passenger vehicle service in the A. E. F. The equipment with the searchlight in place on the body, but with the bows and canvas cover removed is shown in Fig. 41. In this position, the searchlight can easily be operated and can be used for ordinary field searchlight service. The development of this equipment marked a very big advance in the development of searchlight power units, especially and in *mobile* power units particularly.

51. Contemporaneously with the development of the equipment just described, an attempt was made to convert a medium

FIG. 40.



Top view of chassis of 1918 design of mobile searchlight power unit, showing location of 21 kilowatt, 105 volt generator on propeller shaft. The governor is shown to the left of and just below the generator name plate. Hand holes for increasing ventilation are shown just back of the gear shift. The chassis is a standard 145-inch wheel base Cadillac design.

capacity truck into a mobile searchlight power unit. For this purpose, a 2½-ton standard truck chassis was equipped with a 5½-ton standard truck engine, the whole being mounted on pneumatic running gear. A special body was provided and the searchlight mounted thereon. The generator was mounted on the propeller shaft in much the same manner as the unit shown in Fig. 40, excepting that the generator armature was keyed to the propeller shaft. A view of an experimental unit of this type is shown in Fig. 42. It was not successful on account of certain limits of design which had been anticipated. It indicated certain possibilities, however, which might be utilized in future designs.

52. The success of the searchlight power unit design having the generator placed on the propeller shaft was marked. Before

Fig. 41.

View of 1918 design of mobile searchlight power unit and open type searchlight, mounted ready for immediate service.

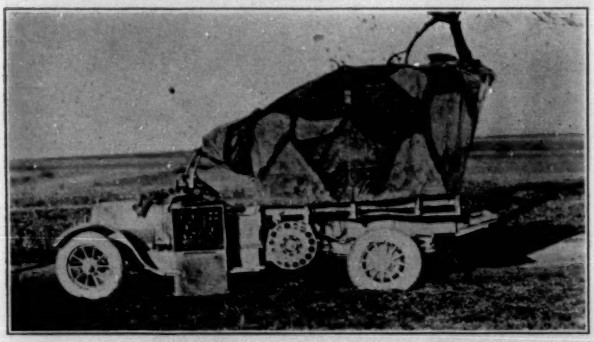
Fig. 42.

Experimental design of mobile searchlight power unit, with open type searchlight, illustrating the adaptation of standard motor truck equipment for searchlight power unit service.

the completion of the first sample, ninety units similar to those shown in Fig. 39 were ordered. These were brought through with great rapidity, since the chassis and generator were standard and the other parts were relatively simple to construct. One of these units is shown in service with the Second Field Army, A. E. F., in Fig. 43.

53. The searchlight power unit development took a definite form in the fall of 1918. Designs were prepared for 6.5-kw. units and 50-kw. units. An outline drawing of the 6.5-kw. size is

FIG. 43.



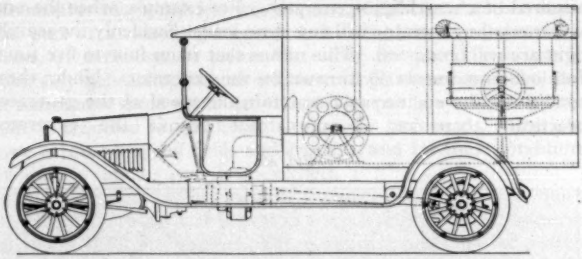
1918 design of searchlight power unit, photographed in the lines of the 2nd Field Army, A. E. F., in France.

shown in Fig. 44. A photograph of the 50-kw. size is shown in Fig. 45.

54. A still further extension of searchlight power unit design was made during the war. It consisted in the installation of two standard 25-kw., 115-volt, stationary gasoline-electric generating sets in a box car. The car axles were provided with electric motors, so that the car could be self-propelled. A sample of this design is shown in Fig. 46. It operated successfully as a power unit and tractor.

55. The essential features of searchlight power units of the mobile type are relatively simple. The engine is one of the principal elements. It must be sufficiently large to drive a generator

Fig. 44.



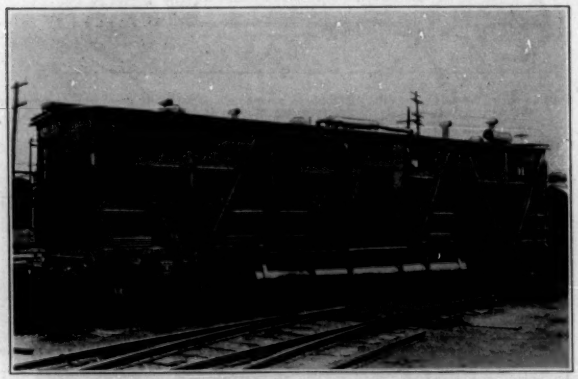
1919 design of 6.5 kilowatt mobile searchlight power unit, illustrating generator on propeller shaft, cable reel and 30-inch open type searchlight. It carries a crew of four men.

Fig. 45.

1919 design of 50 kilowatt mobile searchlight power unit. It carries a crew of twelve men with all of their auxiliaries, a 60-inch, 500 ampere open type searchlight and 500 feet of cable.

for supplying power to a searchlight. It must, at the same time, have such characteristics that it will not fail under the duties required of a searchlight generator. For example, when the unit is started, the generator will run at no load. Suddenly the searchlight arc will be started. This means that from four to five times full load is momentarily thrown on the generator. Under these conditions, the engine must maintain the speed of the generator practically constant. It must not permit the generator

FIG. 46.



1917 design of mobile searchlight power unit, consisting of two standard 125 volt, 25 kilowatt gasoline generating electric sets, mounted in standard box car, specially equipped with electric motors on the wheel axles.

speed to drop down else the voltage will drop and the arc will be extinguished. This means an engine having a torque characteristic of such shape that doubling or tripling the load momentarily will not appreciably alter its speed.

56. The second important characteristic of a searchlight power unit is its radiator. This must be of such design and construction as to permit operating the engine at about one-half to two-thirds of its normal output, when the power unit is stationary in space. It must also be able to sufficiently cool the engine when the power unit is located at high altitudes as well as at low altitudes and in the extreme conditions of summer in near-tropical

countries, as well as in the summer in temperate countries. It means, besides, a radiator of standard construction so as to reduce the number of special features or parts required. Another essential part of a searchlight power unit is the running gear. This must, of necessity, be pneumatic, since the power unit carries relatively delicate apparatus which must be moved over the road at maximum speed up to 40 or 45 miles per hour. Besides, the unit is required to go through relatively bad roads, sometimes even across ploughed fields and swamps, and for these conditions pneumatic running gear is unexcelled.

57. The chassis of a searchlight power unit is relatively unimportant. To be sure, it is best to have a strong enough one, but so far no difficulty has been experienced in adapting for searchlight power unit service any one of the standard chassis frames which are on the market.

58. Searchlight power unit bodies are relatively special. They are required to carry a searchlight, several hundred feet of cable, 12 to 14 or 15 men with all their paraphernalia, so that they may subsist themselves and operate their unit in the field for about six- or seven-day periods. It has been found that the complete live load on a power unit is about 7000 pounds, so that it can readily be seen why it is necessary to have a relatively large lorry chassis for searchlight power unit service.

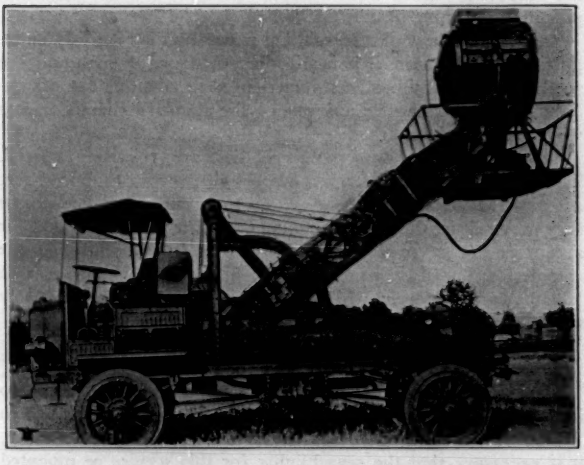
TOWERS.

59. Certain applications of searchlights required them to illuminate targets on the earth's surface at ranges of 12,000 to 15,000 yards. Owing to the curvature of the earth's surface, it is necessary that the searchlights for this service be mounted from 40 feet to 60 feet or even 100 feet above sea level. In certain localities advantage is taken of the natural contour of the earth's surface and the searchlights are mounted on elevated points in the landscape. In many places, however, the contour of the country is such as to prevent installation in suitable natural elevated positions. For these places, various forms of towers have been developed for the mounting of searchlights.

60. Searchlight tower mounts may be roughly divided into two classes. First, mounts fixed in position. Second, mounts mobile. The fixed searchlight tower mounts are rapidly becoming obsolete and for the past few years most of the inventive

talent has been concentrated on the development of mobile searchlight towers and tower mounts. One of the earliest of these is shown in Fig. 47. This illustrates a 36-inch medium intensity barrel type of searchlight mounted on an extensible tower built after the Bascule bridge idea. The entire equipment is carried on a 3½-ton lorry. By means of the tower, the searchlight can be elevated 20 feet above the surrounding terrain. The equip-

FIG. 47.

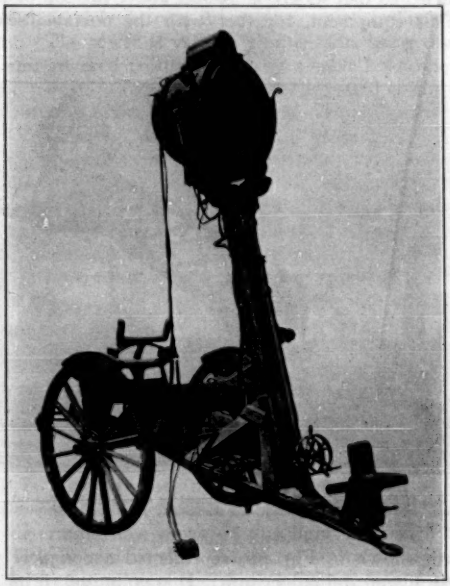


Early design of mobile searchlight tower unit. The tower has a lift of 20 feet and carries a 36-inch, 110 ampere, medium intensity arc, barrel type of searchlight. It is mounted on a 3½ ton truck.

ment was relatively heavy and could only be operated on good roads or ordinary roads. It could not be easily operated cross country or in the fields. Besides, it required a second truck or lorry for carrying the power unit (Fig. 35). Eight of these equipments were used during operations on the Mexican border in 1917, and, so far as their limits permitted, were successful. Experience with them indicated, however, the need for more mobile and more powerful field searchlights on towers. The next attempt at a solution of the problem is shown in Fig. 48.

This illustrates a 24-inch high-intensity arc searchlight mounted on a 16-foot extensible tower. The equipment is placed on a standard artillery gun carriage which, together with the limber shown in Fig. 36, constitutes a complete mobile searchlight unit. The equipment is horse drawn and designed for maximum speed

Fig. 48.

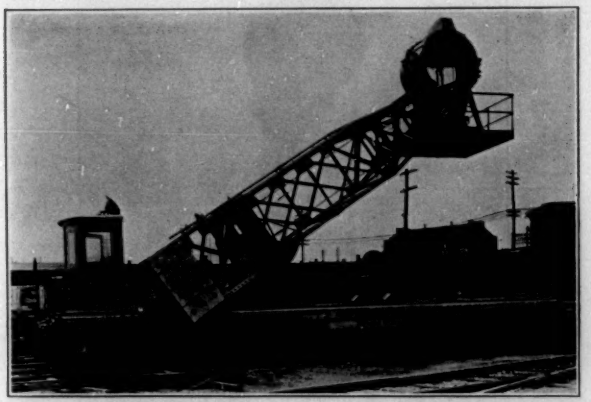


1917 design of tower equipment for a mobile army. It has a 24-inch, 75 ampere high intensity arc searchlight. It is mounted on a mast fixed on an artillery gun carriage, and so arranged that the searchlight may be raised 16 feet above the surrounding terrain.

not to exceed five miles per hour. Eight of these units were sent to France with the First Engineer Train in July, 1918, and within certain limits functioned successfully with the A. E. F. in France. It was found, however, that field searchlights were unsuccessful in trench warfare and the 24-inch searchlights were later dismounted from the towers and used in emplacements.

61. Further developments indicated the necessity for larger mobile searchlights on towers. To meet this situation, a modified form of hinged and counter-weighted tower was designed. It is shown in Fig. 49. It is mounted on a standard railway flat car. It carries a 60-inch coast-defense design, barrel-type, high-intensity arc searchlight. By means of the tower this searchlight can be raised so that its arc is 33 feet above the top of the track rails. This equipment, together with the portable searchlight

FIG. 49.



1918 design of hinged searchlight tower mounted on standard steel flat car. The tower carries a 60-inch, 150 ampere high intensity arc searchlight which can be elevated 33 feet above the surrounding terrain.

power unit shown in Fig. 46, represented a complete portable searchlight tower and power unit. It was limited in its activity, however, to points where standard gauge railway track was available. It was self-propelled at speeds up to ten miles per hour. It weighed, complete, 88 tons.

62. Extreme mobility, however, seemed to be the underlying principle in coast-defense operations, as well as in field operations. For this reason it was deemed essential to design a mobile searchlight tower which could move anywheres. A very intensive study was made of the situation, and, based on a careful survey,

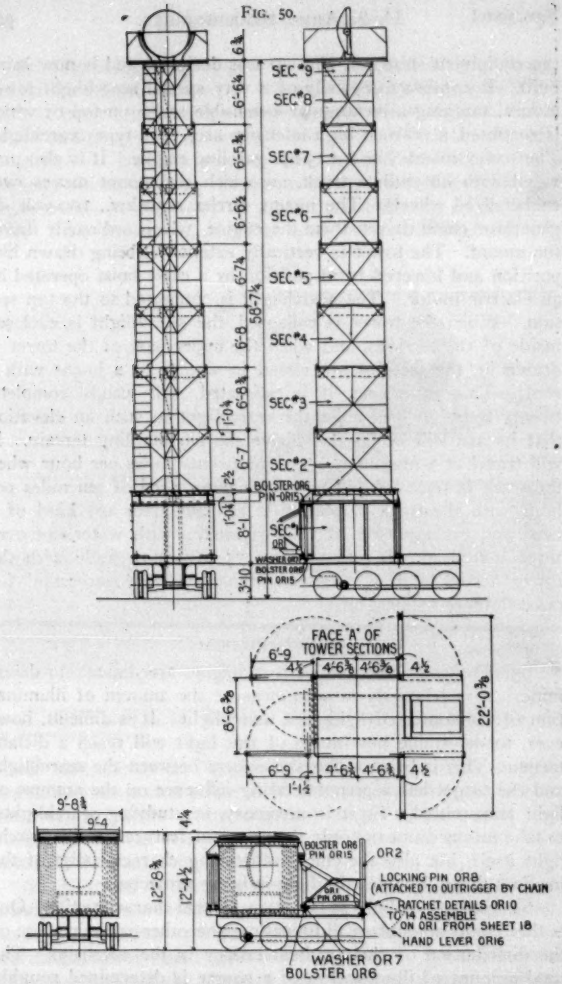
the equipment shown in Fig. 50 was designed and is now being built. It consists essentially of a very special searchlight tower mount, carrying a rectangular extensible tower on top of which is mounted a 60-inch high-intensity arc, open-type searchlight. The tower mount has a 125-hp. gasoline engine. It is also provided with an endless track, on which the mount moves over rubber-tired wheels. The mount carries a 50-kw., 100-volt, dc generator chain driven from the engine, which ordinarily drives the mount. The tower is vertically extensible, being drawn into position and lowered from position by a cable hoist operated by an electric motor. The searchlight is connected to the top section. When the tower is collapsed, the searchlight is enclosed inside of the sections, and when the upper part of the tower is drawn in, the sections are closed in similar to a house with a roof. This equipment, it is estimated, will weigh, complete, twenty tons. It will hoist the searchlight to such an elevation that its arc will be 60 feet above the surrounding terrain. It will travel at a maximum speed of twenty miles per hour when the track is removed and at a maximum speed of ten miles per hour with the track in place. It can negotiate any kind of a road and can even run through a swamp with water not over three feet deep. It will climb a 75 per cent. grade with the tower nested, and will undoubtedly prove very successful for coast-defense applications.

CHARACTERISTICS.

63. The characteristics of searchlights are difficult to determine. It is relatively easy to measure the amount of illumination of the source of light in a searchlight. It is difficult, however, to determine how much of this light will reach a distant target. This is because the atmosphere between the searchlight and the target has a preponderating influence on the amount of light transmitted. So it is necessary, in studying searchlights, to take into account not only the principal features of the searchlight itself, but also the energy absorbing characteristics of the medium through which the light is being projected.

64. Sources of light possess two general characteristics. One is their total amount of illumination, the other is their color or the distribution of their radiant energy in the spectrum. The total amount of illumination of a source is determined roughly

FIG. 50.



1919 design of mobile searchlight tower and mount. Searchlight is 60-inch open type design and can be raised 60 feet above the surrounding terrain by the extensible tower. The entire equipment is carried on an eight wheeled, self-propelled carriage, which in addition carries a 500 ampere generator.

by the temperature at which that source operates and by the amount of energy available for conversion into light. The color of the source or its spectral energy distribution is almost wholly dependent on the maximum temperature of the source. The total amount of energy available as light is usually measured by any one of several well-known photometric schemes. Two of them have been very widely used in the recent investigations of searchlights.

ARC ILLUMINATION.

65. One method of measuring arc illumination uses a standard photometer and several mirrors. The photometer and the source of light are held fixed in position. The mirrors are so arranged that they will reflect the light given from any one sector of the source into the photometer. The mirrors are rotated about the source step by step in three great circles. Photometric observations are made at each step. The observations are repeated in order to insure average conditions and the result is plotted as a characteristic curve. A reproduction of such characteristics for various kinds of searchlight arcs are given in Figs. 51, 52 and 53. These represent not only the distribution of flux of illumination from the source of light, but also the total quantity of light that can be expected in any given portion of the perimeter.

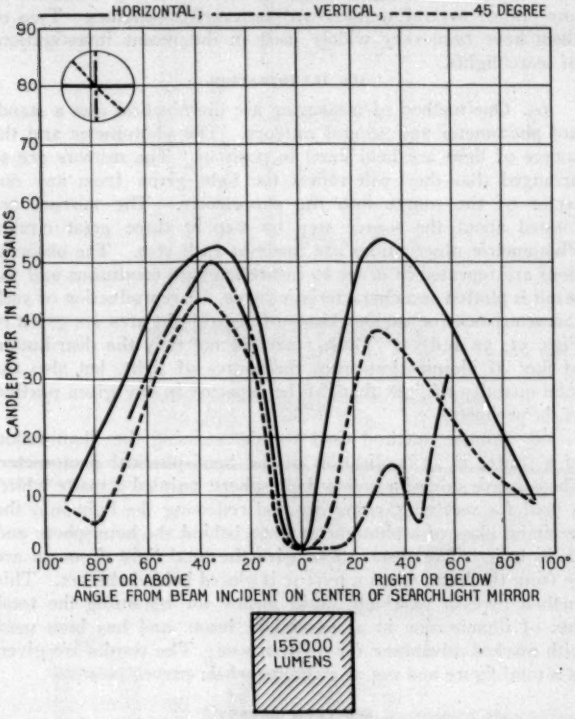
66. Another method used for determining the illumination of a source is an application of the hemispherical photometer. The concave side of a hollow hemisphere, painted a matte white, is used for receiving, collecting and reflecting the light into the receiving glass of a photometer fixed behind the hemisphere and on its axis. The observations give the total light from an arc or from the beam when a mirror is placed behind the arc. This method gives a relatively rapid means for obtaining the total flux of illumination in a searchlight beam, and has been used with marked advantage for this purpose. The results are given as a total figure and not as a characteristic curve.

SPECTRUM ENERGY.

67. Spectrum energy distribution characteristics of sources of light for searchlights are of prime importance. Their form gives the distribution of the light energy in the source. The maximum point of this characteristic gives a clew to the tem-

perature of the source. A study of their shape reveals the efficiency and the usefulness of the source. There are several methods used for obtaining spectral energy distribution. One is

FIG. 51.

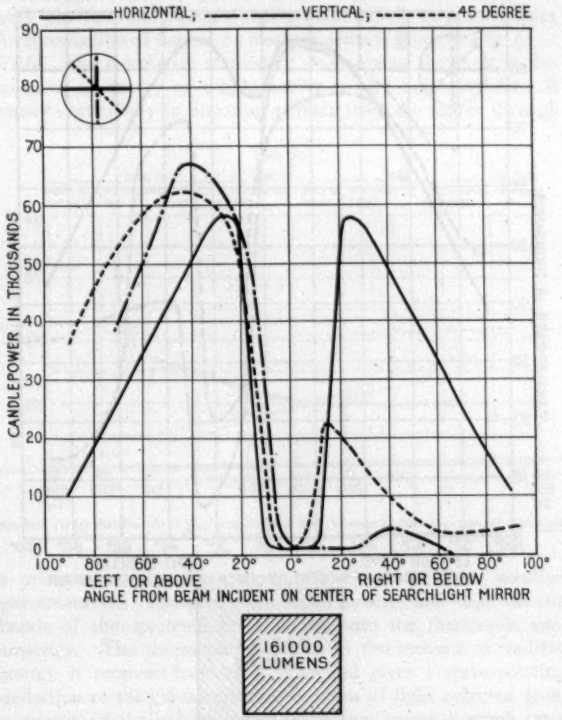


Graph illustrating distribution of illumination of a 195 ampere, 65 volt low intensity searchlight arc.

by the spectro-photometric scheme. The other is by the bolometric scheme. In the spectro-photometric method, a polarization spectro-photometer with a polarization photometer and

illumination box is used with certain auxiliary apparatus. In this apparatus, the source of light, whose spectral distribution is to be examined, is compared with a standard source of light.

Fig. 52.

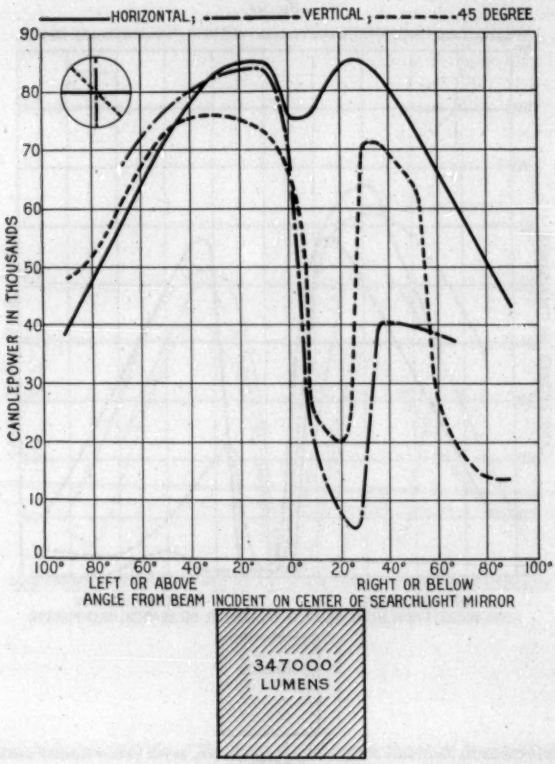


Graph illustrating distribution of illumination of a 200 ampere, 65 volt medium intensity searchlight arc.

For all of the comparisons made during the last two years on searchlights, a 500-watt, type C Mazda lamp was used as a standard. It was operated at a constant voltage of such value

that its characteristics were known. The relative value of the radiant power of the arc under observation as compared to the

FIG. 53.



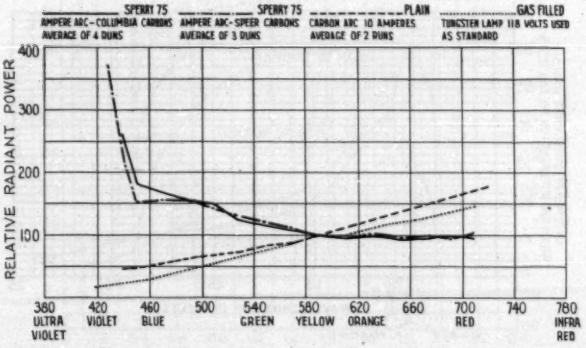
Graph illustrating distribution of illumination of a 150 ampere, 75 volt high intensity searchlight arc.

standard was obtained visually spectro-photometrically. The light from the test source and the comparison source were con-

densed and made to enter the illumination box from opposite sides. In the box they fell on magnesium carbonate blocks. Precautions were taken to eliminate the color difference between the intensely white light of the searchlamp source and the relatively yellow light from the type C Mazda lamp. The measurements were laborious and tiresome, but gave relatively accurate results. A reproduction of one set of measurements is given in Fig. 54.

68. The bolometric method of determining the spectral distribution of energy of a light source is very much simpler. It consists essentially in directing a beam from the source through

Fig. 54.



Spectral energy distribution of high intensity arcs used for searchlights, as compared with plain carbon arc and gas filled tungsten lamp. Wave lengths are in 10^{-5} meters.

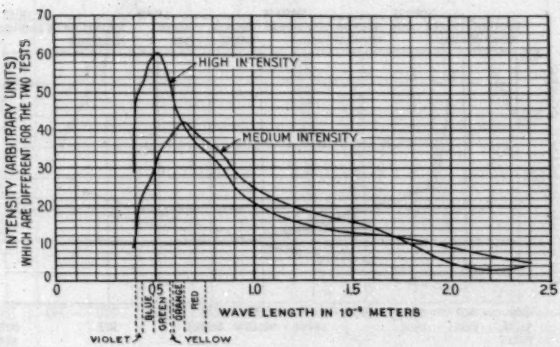
a prism onto a sensitive thermopile, connected to a sensitive galvanometer. The prism is rotated slowly, and thus various bands of the spectrum are directed onto the thermopile successively. The thermopile responds to the amount of radiant energy it receives from each band and gives a corresponding deflection to the galvanometer. A beam of light reflected from a mirror on the galvanometer suspension traces a graph on a rotating sensitive film, suitably placed. The result is an accurate graph showing the distribution of radiant energy in the spectrum, taken without the direct aid of any human organ. This equipment has been principally used for observing the spectral dis-

tribution of energy in searchlight beams rather than sources of light. Characteristics so taken are given in Fig. 55.

ATMOSPHERIC ABSORPTION.

69. The effect of the absorption of radiant energy by the atmosphere has been studied from time to time. It is found that the energy-absorbing characteristics of the atmosphere vary through very wide limits and are affected by many factors for which there are at present no well-established standards of measurement. For example, the present meteorological determina-

FIG. 55.



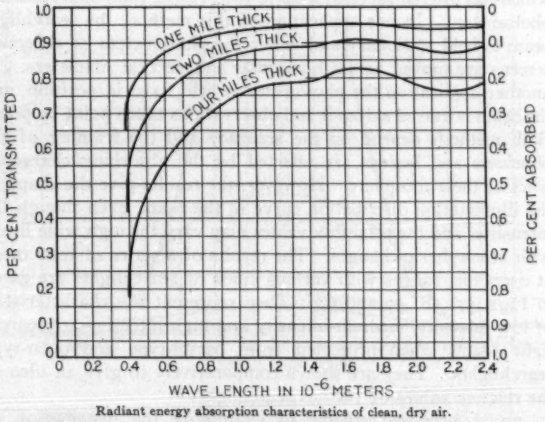
Spectrum energy distribution in beams of high intensity and medium intensity arc searchlights.

tions give the amount of moisture in the atmosphere, but do not state how this moisture is distributed. It may be in the form of a mist composed of very fine drops or it may be in the form of a rain composed of relatively large drops. The mist is an almost impenetrable screen for a searchlight beam, while the rain curtain can easily be penetrated. Then again, the amount of dust in the atmosphere is an important feature, tending to reduce the amount of light transmitted from a searchlight source. Hence, it is seen that a study of the atmosphere is relatively important in connection with a study of searchlight characteristics. On the other hand, it must be realized that the searchlight must be used under all atmospheric conditions. For this

reason, while a knowledge of the various atmospheric conditions will be of advantage in the operation of searchlights, yet it is not fundamentally necessary. For a thorough consideration, however, of searchlight characteristics, a general idea of the effect of atmospheric absorption is quite important.

70. Tests have been made of atmospheric absorption during a long period of time by the physicists of the Smithsonian Institution. The results of their investigations are shown in Fig. 56. It is seen that layers of air, such as are used in ordinary search-

Fig. 56.



Radiant energy absorption characteristics of clean, dry air.

light illumination, absorb a very large quantity of the light flux produced at the source, and thereby the atmosphere introduces an important absorbing factor in searchlight operation. These characteristics also indicate the more rapid dissipation of the shorter wave-lengths of radiant energy than of the longer wave-lengths. One result of this is to make a white source appear yellow at a distance of 15 to 20 miles. Another effect is to partially nullify the illuminating value of the high-efficiency (intensity) arcs. These have a maximum in the green, while the medium-intensity arcs have a maximum in the yellow. The high-intensity arcs have a larger proportion of blue light than

do the medium-intensity arcs. However, since the radiant energy in the blue portion of the spectrum is very much more rapidly dissipated in the atmosphere than is the radiant energy in the yellow and red portion, it is found that a greater amount of the radiant energy produced by the high-efficiency arcs is absorbed in the atmosphere than is the radiant energy from the medium-intensity arcs.

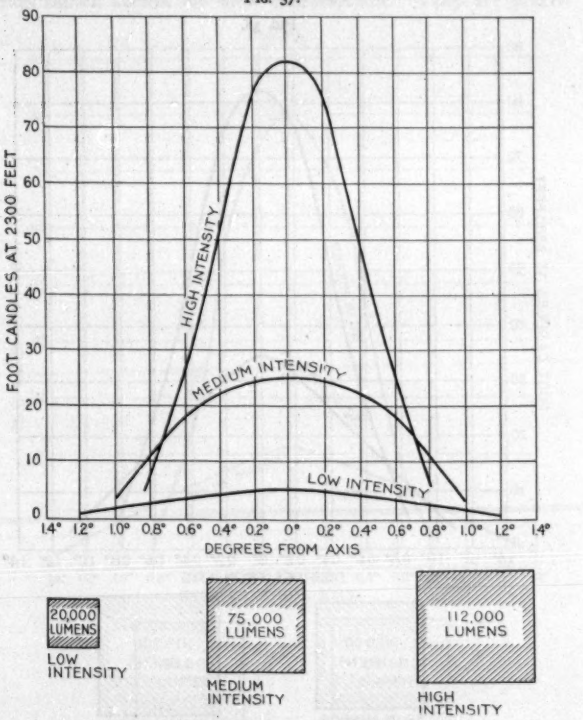
BEAM ILLUMINATION.

71. The photometering of searchlight beams has proven relatively difficult. Several methods have been tried. The only one which has proven successful up to the present time uses standard photometers. In one application of this method, the searchlight beam is held stationary and either the photometers or reflecting screens are moved across horizontal and vertical diameters. In another application the photometer is held fixed in position, and the beam is moved across it and observations taken point by point. Both methods depend on the accuracy and the training of the observers and besides are affected by the absorbing characteristics of the atmosphere. However, the results give the shape of the illumination distribution curve in the beam, even though the intensities and the total flux values may vary through wide limits with atmospheric changes. The results of a series of tests made at 2300 feet ranges with various kinds of searchlights are given in Figs. 57, 58, 59 and 60. They represent the characteristics of low-intensity, medium-intensity and high-intensity arc searchlight beams when projected from barrel-type and open-type searchlights. They are shown comparatively to give an idea of the relative values of various searchlights.

72. A proposed scheme of examining the distribution of illumination in a searchlight beam is an application of the bolometer with a suitable correcting screen. The screen consists essentially of a cell containing a liquid which passes radiant energy in practically the same proportion as the eye is influenced by it. The light, after passing through the cell, is projected onto a sensitive thermopile which is connected to a reflecting galvanometer. A number of these instruments may be placed across the horizontal and vertical diameters of a searchlight beam and practically simultaneous observations obtained of the deflections of the galvanometers. This method may be used for measuring the absolute distribution of energy or the relative distribution

of energy in the beams. The character depends upon the source used as a standard. This scheme has been tried and found

Fig. 57.



Comparative flux distribution of illumination in beams of low intensity, medium intensity and high intensity arc barrel type searchlights.

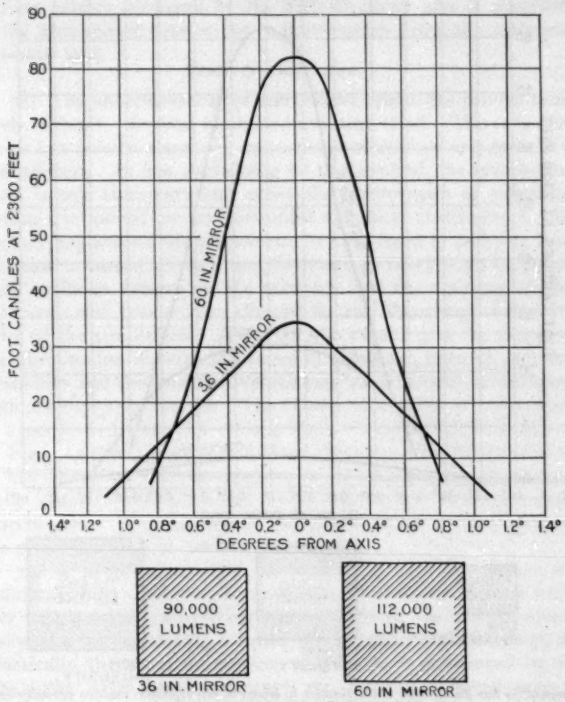
effective. It has not, however, been developed to a point of wide application.

TARGET COMPARISONS.

73. The most useful method of examining a searchlight beam is in connection with the type of target with which it will be used.

Recently a number of tests have been made at one of the large aviation stations where moving airplanes were used as targets. Various kinds of searchlights were tested in combination with the

FIG. 58.

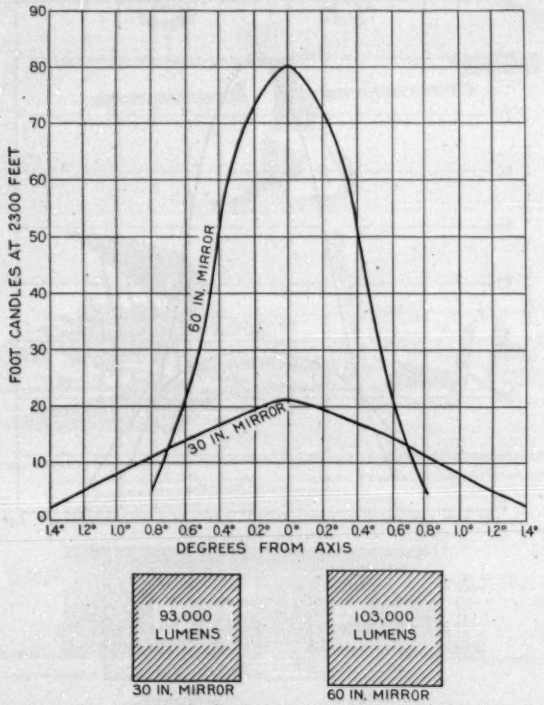


Comparison of flux and illumination distribution in beams of 36-inch and 60-inch barrel type of searchlights, both having the same light sources.

airplanes. The searchlights have been described on preceding pages. The type of airplane used is shown in Fig. 61. The results of the tests which give characteristic pick-up values for the searchlights are shown in Figs. 62, 63 and 64. These illustrate

what might be termed "the range characteristics of searchlights used in picking up airplanes." It should be noted that all of the curves shown exhibit the same characteristic. They are practi-

Fig. 59.

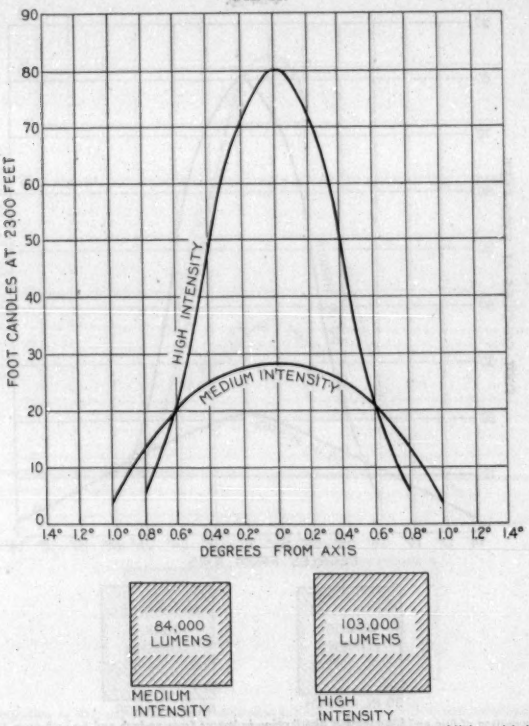


Comparison of flux and illumination distribution in beams from 30-inch and 60-inch open type searchlights, both having the same light sources.

cally flat up to a limiting point beyond which they rapidly drop away until a second limiting point is reached, at which they more gradually approach an asymptotic relation. The first point at which a change in the curvature occurs is probably caused by the

difference in the observing powers of the eyes of the observers. The second point of curvature in the characteristic is probably caused by the approach of the threshold of vision of the various

FIG. 60.



Comparison of flux and illumination in beams from 60-inch open type searchlights with high intensity and medium intensity arc light sources.

observers. In this connection it is interesting to note that the same observers have been able to pick up airplanes at about twice the range in daylight as they pick them up at night with the searchlight, whose characteristic is shown in Fig. 63.

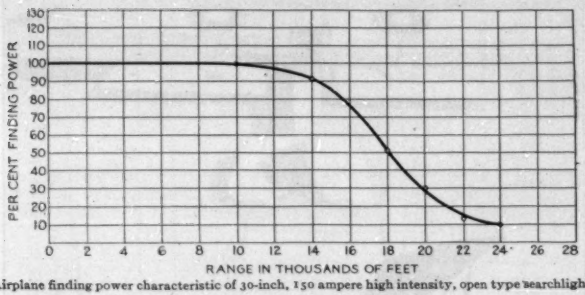
Fig. 61

Typical airplanes such as used for making target comparison tests.

BEAM COLOR.

74. A great deal is said from time to time concerning the best color of the beam of a searchlight. This characteristic has

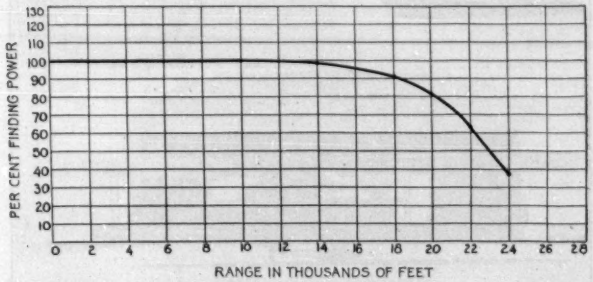
FIG. 62.



Airplane finding power characteristic of 30-inch, 150 ampere high intensity, open type searchlight

been found to be dependent principally upon the temperature of the source and the kind of mirror. At relatively low temperatures, that is, with low intensity arcs having a current density

FIG. 63.



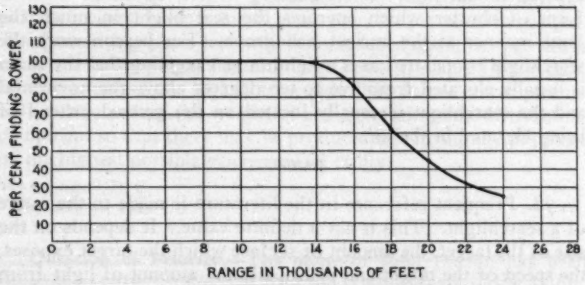
Airplane finding power characteristic of 60-inch, 150 ampere high intensity, open type searchlight

of about 0.3 amp./sq. mm., the color is reddish yellow. Ingredients in the cores of the carbons can be used to modify the color of the beam. At intermediate temperatures, such as produced by medium-intensity arcs having current density about 0.6 amp./sq.

mm., the color of the beam is greenish yellow. Ingredients in the cores of electrodes have slight modifying effect on the color. At high temperatures, such as produced by high-intensity arcs with a current density of about 1.0 amp./sq. mm. the beam color is bluish white and is uninfluenced by ingredients in the cores of the electrodes.

75. The color of a searchlight beam can be accurately controlled by the use of a ray filter. Such filters, however, reduce the amount of light in the beam from 20 to 50 or more per cent. Their use has been abandoned for military purposes where the amount of light is of paramount importance. Besides, it has

Fig. 64.



Airplane finding power characteristic of 60-inch, 200 ampere medium intensity, open type searchlight

been found that the color of the light is not nearly so important as the quantity of it and its distribution.

TACTICS.

76. The tactical operation of searchlights varies with the kind of military situation to be met. Before the advent of the airplane, searchlights were used for illuminating bodies of troops, battleships and other objects on the earth's surface. Such objects were relatively slow moving and at the same time relatively large in size. They moved in one plane and as much as thirty minutes or even two hours could be allowed for finding them. The method used was to sweep the landscape slowly until the target was picked up, then the light would be held fixed on it for such

offensive operations as had been determined. The advent of the airplane in warfare, however, changed the tactical operation of searchlights. They were required to search in three dimensional space instead of in a plane. This increased the difficulty many fold. Beside, the targets were relatively small in size, fast in speed and agile in movement. In addition, the development of accurate range-finding devices reduced the time that a searchlight beam could be safely exposed. As a result, the *time* of searching has been reduced to a maximum of about thirty *seconds* and the *method* of searching radically changed.

77. Searchlights are also used in military operations for signalling between distant points, particularly in day time and as beacons for airships. The signalling is done by means of some form of shutter which operates the searchlight in much the same manner as the ancient heliograph. For beacon work the searchlight is operated as is a lighthouse, excepting that the beam is usually elevated from five to ten degrees above the horizontal and the searchlight is usually located on the ground instead of being elevated in the air.

RANGE.

78. Frequent reference in the literature is made to the range of a searchlight. This is not a definite value. It depends on the size of the target, the amount of surface which the target exposes, the speed of the target and principally the amount of light from the source and the absorbing qualities of the intervening atmosphere. The usual range at which an airplane can be picked up is about 15,000 feet, while the same searchlight can usually pick up a battleship at 40,000 to 50,000 feet. These values apply only to relatively clear weather. On foggy nights it is impossible to pick up either the airship or the battleship at 2000 feet, while on rainy nights the range for the two types of targets may be 10,000 and 30,000 feet respectively. The high-intensity arc searchlights can pick up a target at a greater range than can the medium-intensity searchlights. This is, however, due to the fact that for the same energy input the high-intensity arcs give a greater total light flux at the source than do the medium intensity arcs. It has been found, however, that where both kinds of arcs have the same amount of flux at the source that the medium-intensity arc had a greater range than the high-intensity arc.

Of course, this increased range is obtained with the expenditure of more energy in one case than in the other.

FUTURE.

79. The future development and use of searchlights seems assured. The increasing use of night operations in military manœuvres requires a wider application of means for detecting and illuminating the enemy. This means that more than ever before use will be made of searchlights in limiting enemy operations.

80. The development of searchlights will probably proceed along lines which will reduce the weight of the equipment and increase its effectiveness. The searchlight itself has, within the past two years, been reduced more than 80 per cent. in weight. The generating plant has only been reduced about 20 per cent., while the cable weight has only been reduced about 15 per cent. It seems, therefore, logical to expect that future developments will seek to reduce the weight of the generating and distributing equipment so that there may be produced a searchlight equipment of the highest possible efficiency and utility.

Washington, D. C.,
February 11, 1920.

Question of Priority.—The name of John Dalton has been for over a century connected with the establishment of the atomic theory as generally applied in chemistry, but his claims to the foundation of it have been disputed in a paper recently published by Andrew Norman Meldrum, I.E.S., Fellow of Bombay University. Meldrum's paper is fundamentally a criticism of the presidential address of Alexander Scott, delivered March 29, 1917, at the annual general meeting of the Chemical Society. Scott's subject was "The Atomic Theory," with especial reference to the work of Stas and Prout's hypothesis. According to Meldrum, many of the statements in the address are open to criticism, both as to data and inferences, but the most interesting point is the claim that William Higgins, who was an early convert to the antiphlogiston views of Lavoisier, anticipated Dalton by about fourteen years in the suggestion of the atomic theory. Meldrum traces the development of the theory back to Newton, who advanced the view that an elastic fluid is composed of particles mutually repellent. Quite a number of other scientists of the seventeenth century were more or less connected with the development of the theory, one important reason for such interest being that they

were, as was the custom at that time, good classical scholars and, therefore, familiar at first hand with the early Greek philosophers, who, as is pointed out in our histories of chemistry, suggested a theory of the composition of matter which is singularly like that dominant to-day. Meldrum's essay "The Development of the Atomic Theory" is interesting throughout.

H. L.

On the Electrical Conductivity of Copper Fused with Mica. SUB-LIEUT. A. L. WILLIAMS. (*Phil. Mag.*, September, 1920.)—To prepare the material an electric arc was struck between an iron or copper plate serving as an anode and a carbon rod as cathode. The arc was shifted over to the mixture of copper and mica lying on the plate and fusion followed. "In making up the samples studied, about equal proportions of copper and mica were used." The resulting material seems to be uniform throughout, about as hard as glass and more brittle than copper. It is malleable at 2000° C. The outstanding characteristic is the great reduction in its electrical resistance caused by an increase of temperature. A specimen whose resistance was 91,010 ohms at 99° C. was found to have only 11,370 ohms at 228° C. For another specimen the data are 16,000 ohms at 27° C. and .5 ohm at 850° C. For mixtures of iron and mica similar results were obtained.

The author makes the suggestion that the copper-mica mixtures may prove of use in signalling and in sound-ranging "as the changes of resistance, due to changes of temperature, are quite considerable, being some thousands of ohms per degree centigrade with some samples."

Prof. J. C. McLennan of the University of Toronto has caused the experiments to be repeated and extended in his laboratory by Miss Mackey and Miss Giles. Some of the results above quoted are from their data.

G. F. S.

High Altitudes in the United States. (*U. S. Geological Survey Press Bulletin* No. 457, October, 1920.)—Many people believe that Mount Washington, in New Hampshire, is the highest mountain in the eastern part of the United States. Mount Washington stands 6293 feet above sea level, according to the Survey, but many peaks in the Southern Appalachians are several hundred feet higher than New Hampshire's famous mountain. The highest mountain in the Appalachian system—the highest point in the United States east of the Rockies—is Mount Mitchell, in North Carolina, which stands at an elevation of 6711 feet. The highest mountain in Tennessee, Mount Guyot, stands 6636 feet above sea level.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

RECOMMENDED SPECIFICATIONS FOR VOLATILE MINERAL SPIRITS FOR THINNING PAINTS.[1]

[ABSTRACT.]

THIS specification, prepared under the auspices of the Bureau of Standards, is one of the series of specifications for paint materials approved by an interdepartmental committee of Government experts. In addition to the general statement of requirements, there are given detailed instructions as to sampling, laboratory examination, and basis of purchase. The standards were finally submitted to representatives of the petroleum and the paint and varnish industries and the suggestions considered in the final revision.

AIR FORCES ON CIRCULAR CYLINDERS, AXES NORMAL TO THE WIND, WITH SPECIAL REFERENCE TO DYNAMICAL SIMILARITY.[2]

By Hugh L. Dryden.

[ABSTRACT.]

ONE of the most difficult problems of the airplane designer is to obtain a method of computing forces on full-size machines or full-size machine parts from measurements made on models in a wind tunnel. A certain equation deduced from theoretical considerations has long been known and used, namely, the equation proposed a long time ago, first by Helmholtz, later stated by Reynolds and developed more fully by Lord Rayleigh and Buckingham. This equation is a logical consequence of certain assumptions and states that, if these assumptions are true, the force of a current of air upon a solid body may be expressed as $C\rho AV^2$, ρ being the density of the air, A the area of the body projected on a plane normal to the wind, V the velocity of the

* Communicated by the Director.

[1] Circular No. 98.

[2] Scientific Paper No. 394.

wind, and C a dimensionless constant depending on a single parameter $\frac{VL}{\nu}$, where ν is the kinematic viscosity of the air and L is a linear dimension of the body. This equation then implies that if C be plotted against $\frac{VL}{\nu}$, the points will fall on the same curve independent of the individual value of V or L, provided the bodies are geometrically similar and presented in the same manner to the wind.

This law is a logical consequence of the assumptions. Although some tests have been made of the validity of the assumptions in the case of wind-tunnel experiments, no extensive investigation of a body of simple geometrical form over a large range of values of V and L has been published. The present paper gives the results of tests on cylinders for different values of L. An attempt was made to make the assumptions involved in the derivation of the equation true as closely as is possible in wind-tunnel experiments.

Cylinders of 1, 1¼, 1½, 1¾, 2, 2½, 3, 4, 4½, 5, 5½, and 6 in. (.0254 to .1524 m.) were used at velocities from 15 to (in the case of the smaller cylinders) 80 miles per hour (25 to 130 km. per hour approximately). The range of values of $\frac{VL}{\nu}$ was from 10,000 to 185,000. The cylinders were made of wood with the exception of those less than 2 in. in diameter, which were of brass; but an additional 1-in. wood cylinder and 4-in. brass cylinder were also used. The "guard ring" principle was used to obtain results applicable to infinite cylinders.

The results show that the equation does not represent the facts of wind-tunnel experiments in the case of cylinders. The coefficient C for a 1-in. cylinder is half again as large as that for a 3-in. cylinder at the same value of $\frac{VL}{\nu}$. Above a 3-in. diameter the equation is satisfied closely, the coefficient being practically constant and equal to 0.426. The curve for the 1-in. cylinder checks N.P.L. values closely. The maximum departure of any one observation from the mean is about 2½ per cent. Measurements of the pressure distribution showed that in the case of the small cylinders the ratio of the average decrease in pressure on the back to the maximum increase in pressure on the front is greater than in the case of the larger cylinders.

CAST IRON FOR LOCOMOTIVE CYLINDER PARTS.[1]

By C. H. Strand.

[ABSTRACT.]

FREQUENT renewal of cylinder parts of locomotives results in greatly increased cost of maintenance to the railroads, and consequently the quality of the cast-iron entering into their construction is a matter of paramount importance, particularly from the standpoint of wear. These parts include piston-valve bushings, piston-valve packing rings, piston-valve bull rings, cylinder bushings, piston packing rings and piston-head or bull rings. It was found that ordinary high-silicon cast-iron gave unsatisfactory wear, particularly in modern superheater locomotives, and the tendency has been towards a harder and stronger iron.

At the request of the U. S. Railroad Administration, the Bureau of Standards has investigated the mechanical, chemical, and microscopical properties of a number of packing rings furnished with service mileage records, as well as arbitration-test bars, chill-test specimens, and miscellaneous samples from different manufacturers. All of this material was cast-iron such as used for the various cylinder parts. The Bureau of Standards at the same time made a review of the previous work and specifications on this subject, to ascertain as far as possible the practices of the different foundries, and to suggest such revision of existing specifications as would be warranted by the results of the present and other investigations.

It was found that air-furnace iron is more uniform in character and in general of somewhat better mechanical properties than cupola iron. The latter, however, often equals or even excels the air-furnace product in mechanical properties. Because of the many variable factors, it was difficult to establish correlation between laboratory and service tests. It was recommended, as a result of the present and other investigations, that the transverse-strength requirements of the Standard American Society for Testing Materials 1¼-inch Arbitration Bar be increased from 3200 to 3500 lb. for castings ½ in. or less in thickness, and from 3500 to 3800 lb. for castings over ½ in. in thickness.

[1] Technologic Paper No. 172.

RELATION OF THE HIGH-TEMPERATURE TREATMENT OF HIGH-SPEED STEEL TO SECONDARY HARDENING AND RED HARDNESS.[4]

By Howard Scott.

[ABSTRACT.]

THERE has been more or less mystery attached to certain well-known phenomena connected with the heat treatment of high-speed steel. Anticipating a disappearance of the mystery with the acquirement of sufficient pertinent experimental data, the physical characteristics and the microstructure of a standard type of high-speed steel as affected by quenching temperature, tempering temperature, and treatment below ordinary temperatures were studied.

The experimental results obtained appear to warrant the following conclusions: (1) Secondary hardening necessitates prior partial austenitization produced by the high-temperature treatment; (2) the variations with heat treatment in physical properties and microstructure of high-speed steel are analogous to those of hypereutectoid carbon steel with the exception of the microstructure of hardened but untempered steel; (3) red hardness is largely a function of the composition of the matrix and is only comparatively slightly affected by the amount of dissolved carbide. Three reasons are given for the established advantages derived from the use of the high-temperature heat treatment, namely, increased red hardness, increased initial hardness, and reduced brittleness.

THERMAL AND PHYSICAL CHANGES ACCOMPANYING THE HEATING OF HARDENED CARBON STEELS.[5]

By Howard Scott and H. Gretchen Movius.

[ABSTRACT.]

THERMAL analysis was used here for determining the thermal characteristics of hardened carbon steels below A_1. A definite heat evolution, called Act, was observed for a normal rate of heating starting at about 165° C., reaching a maximum at 270° C. and ending at 290° C.; the effect on it of the variables—rate of heating, tempering, carbon content, and quenching temperature—was studied.

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[4] Scientific Paper No. 395.
[5] Scientific Paper No. 396.

It is shown that for a very slow rate of heating this transformation is practically independent of carbon content, and that it then ends at about 260° C. This temperature undoubtedly represents the end of the transition of martensite into the troostite of tempering. The transformation is also closely associated with the physical changes accompanying the tempering of hardened steel.

A STUDY OF THE RELATION BETWEEN THE BRINELL HARDNESS AND THE GRAIN SIZE OF ANNEALED CARBON STEELS.*

By Henry S. Rawdon and Emilio Jimeno Gil.

[ABSTRACT.]

IN some of the simple alloys a rather definite relation exists between grain size and hardness. A study was made of five types of carbon steel in various conditions of grain size to determine whether such a relation exists for steels. The variations in grain size were produced by annealing for long periods at different temperatures and also by low-temperature annealing after a preliminary straining of the metal. Two methods were used for obtaining the hardness values, the standard Brinell apparatus and a small type, designated as the "micro-Brinell" testing set, by which the hardness of individual grains could be measured.

In general there appears to be no definite relation between grain size and Brinell hardness, except in the case of a very pronounced increase in grain size, which is usually accompanied by a decrease in the hardness.

The general effect of heating steel, *i.e.*, in annealing, is to harden it appreciably, this increase in hardness is noticeable in spite of any sharp drop which may accompany an abrupt change of grain size.

The rate at which steels are cooled, and consequently the structural condition of the hardening constituent, affects the hardness much more than any other factor.

Incidental to the study of the hardness of steels coarsened by annealing after permanent strain, some data were obtained relative to the magnitude of the necessary stress required to cause pronounced grain growth upon annealing such strained metal below the A_1 transformation temperature.

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* Scientific Paper No. 397.

Platinum in 1919. (*U. S. Geological Survey Press Bulletin* No. 457, October, 1920.)—The United States is still dependent on foreign countries for its supply of platinum. The small output of crude platinum from domestic mines increased from 647 ounces in 1918 to 824 ounces in 1919, but the total quantity of refined platinum and allied metals recovered from foreign and domestic ores by domestic refiners decreased from 59,753 ounces in 1918 to 45,109 ounces in 1919. Only 11,759 ounces of refined platinum were derived from domestic ores in 1919. On the other hand, the imports of platinum and allied metals increased from 56,753 ounces in 1918 to 68,054 ounces in 1919, nearly half of which came from Colombia. The estimated world's production increased from 62,283 ounces in 1918, the lowest recorded output, to 67,180 ounces in 1919, but was still far below that of preceding years.

During the war 83 per cent. of the platinum metals consumed in this country were used in essential industries (chemical, electrical, and dental), but in 1919 only 40 per cent. were so used, and the quantity used for jewelry increased from 12 to 56 per cent. The remaining small percentage was divided among several minor uses.

A report on "Platinum and Allied Metals in 1919," by J. M. Hill, recently issued by the Survey, shows the production, consumption, market, and prices, and contains notes on deposits and mining in the United States and the leading foreign countries.

A New Primary Electric Cell. (*La Nature*, September 18, 1920.)—During the war the French army needed a great number of cells of the Leclanché type. France had no manganese dioxide and it was difficult to obtain it from the outside world. Féry succeeded in devising a cell which does not polarize in spite of its lack of the dioxide. At the bottom of the solution is a flat horizontal plate of zinc, to which is soldered a wire forming one terminal of the cell. A cylindrical, porous carbon rests on a thin piece of insulating material which is supported by the zinc. The carbon carries a terminal post. As soon as the current flows hydrogen forms on the part of the carbon close to the zinc. The superficial layers of the liquid have absorbed oxygen from the air. The upper part of the carbon is therefore in a liquid rich in oxygen while the lower part is coated with hydrogen. A gas cell results, the upper part of the carbon being positive and the lower part negative. In consequence of this oxygen is liberated at the lower part and combines with the hydrogen, causing polarization. Hydrogen is set free at the upper end of the carbon and combines with the dissolved oxygen. The operation of the cell therefore depends on the action of oxygen dissolved from the air.

The salt of ammonia is regenerated within the cell, there are no creeping salts and the zinc is not attacked on open circuit. A reduction in cost results from the elimination of the manganese dioxide.

G. F. S.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

BACTERIAL DECOMPOSITION OF SALMON.[1]

By Albert C. Hunter.

[ABSTRACT.]

AN extended bacteriological study was made of salmon held at temperatures between 50° F. and 70° F. until they had reached an advanced stage of decomposition. At twenty-four-hour periods total counts of bacteria were made on the muscular tissue of the back and belly, and agar slant cultures were made from the mouth, gills, stomach, cæca, intestines, heart, liver, and kidney. Experiments were conducted to determine the effect of thoroughly washing the fish as soon as they were brought ashore. The results may be summarized as follows:

1. The muscular tissue of freshly caught salmon is sterile.

2. After ninety-six hours at temperatures between 50° F. and 70° F., the total count of bacteria in the muscular tissue has been found to be as high as 155,000,000 per gram. The high counts obtained are sufficient to explain the decomposition of the tissue.

3. Thoroughly washing the fish on arrival at the dock results in lower total counts. The washed fish decompose less rapidly than the unwashed fish.

4. The mouths and gills of salmon contain living microorganisms of various kinds, even when fresh from the water.

5. The digestive tract of salmon is sterile when there is no food present.

6. The various organs of the body become infected through the blood-vessels, usually within ninety-six hours after the fish are caught.

7. Salmon out of water more than forty-eight hours at temperatures between 50° F. and 70° F. are decomposed to such an extent that they are not desirable as food.

* Communicated by the Chief of the Bureau.

[1] Published in *J. Bact.*

POPULAR NAMES OF CRUDE DRUGS.[1]

By Arno Viehoever.

[ABSTRACT.]

THE purpose of this article is simply to advocate greater care in the use of common names. Where the product is already well known, even by a name which is obviously unsatisfactory, the desirability for another, though proper name, might not be so apparent. In cases, however, where new products are introduced, it is essential that some thought be given to the proper common, as well as scientific, name. A name may already be attached to the product, given to it by some one qualified or not qualified. Discrimination must therefore be used in the choice, and great care in the creation of a name, if no suitable name is available.

After discussing the varied bases of common names for crude drugs, the following rules are suggested for selecting common names, which may prove of value in the consideration of a suitable trade name:

1. The name should preferably be derived from the scientific name, representing an abbreviation, modification or translation of the meaning of the Latin scientific name.
2. No name should be chosen which is used already for a plant or plant product distinctly different in certain respects. This rule should be followed especially in case where these products are derived from plants not very closely related, belonging, for instance, to different genera or families.
3. Preferably the name should indicate or suggest the specific characters of the product.
4. The statement of the country of origin is often useful, although the importance has decreased with extent of cultivation.
5. The selection of a term adaptable to international use appears advisable.
6. The name should be rather short, easy to spell and remember.

[1] In *J. Amer. Pharm. Assoc.*, Vol. ix, No. 7, July, 1920, pp. 671–676.

After discussing a number of new terms, based on these rules and given to products which have recently come on the market, the conclusion is reached that a great number of botanicals have been reported to be valuable for one disease or another. These have been given different common names in different localities, names too often not descriptive and not definite. Instances have been observed where plants, evidently very closely related, have been classified in different genera, if not families; and *vice versa*, where plants have been thrown together, because characteristics observed by a superficial study suggested closer relationship than existed.

The task ahead is to utilize the broader training given to-day to botanists, chemists, pharmacologists, and especially pharmacists, and bring about a further improvement of the science which has to do with the proper classification of our botanicals, based on floral characteristics, but preferably on general morphological, anatomical, chemical, and physiological characteristics. The common trade name then established on the basis of the scientific identification and certain rules agreed upon should do away with many loose terms which are still in common use, or are apt to become popular by misapplication, causing confusion, mistakes, and difficulties of varying consequence.

Technical Notes, Forest Products Laboratory.—The following items are abstracted from the bulletin dated October 15, 1920.

Charring Does Not Preserve Wood.—Tests show that the charring of fence-posts and telegraph poles so long practiced, does not appreciably delay the rotting, in fact, in the experiments, the charred posts decayed more quickly than the uncharred. Theoretically, such treatment should have a preservative action, as charcoal is not subject to the action of living organisms or ordinary oxidation, but the covering is by no means complete. If posts are seasoned before being charred, the charring does not reach the bottom of the season checks, and if charred before seasoning, the covering will open in places as the seasoning occurs. Thus, in either case, the uncharred interior of the wood may become a prey to the destructive agencies. Charring deep enough to accomplish any good weakens the post too much.

Paper From Veneer Waste.—The waste from veneer factories seems to be a valuable source for the manufacture of a high-grade pulp. The cores of many kinds of woods now used only for fuel would be suitable, and, in addition, the clippings and smaller waste amounting to about 20 per cent. of the product could be used. Among the woods thus applicable are: red gum, yellow poplar,

cottonwood, birch, tupelo, basswood, and beech. Many veneer factories are within shipping distance of pulp mills, and in other cases the factories are so grouped that it would be commercially profitable to erect a pulp mill to deal with their waste.

Preventing Decay of Mine-timbers.—Great quantities of valuable timber are being placed in the mines of the nation without any protection against decay. Experiments showed that timbers treated with coal-tar creosote installed in an Alabama mine remained sound for ten years, while all the untreated ones had to be removed. Four-fifths of the treated timbers were still good. Creosote is the most effective preventive of decay, but is objectionable on account of the fire-risk. Sodium fluoride and zinc chloride are odorless, and possibly diminish the fire-risk. They are cheaper than creosote and may be injected by the steeping, open-tank, or pressure methods. The saving is so marked that it will be profitable for all mines to use some process.

Water Solubility a Necessary Property of Wood Preservatives.—Every substance used for wood preservation must be sufficiently soluble in water to produce a toxic solution, but with very poisonous substances this solubility need not be great. In some cases a solubility of one per million is enough. The two mineral preservatives generally noted, sodium fluoride and zinc chloride, are freely soluble in water, but the creosotes are but sparingly soluble as a whole. It appears, however, that some of the ingredients of the creosote oils are sufficiently soluble to render the water toxic. The non-toxic oils are said to act as reservoirs of the toxic ingredients and feed them out slowly to the wood. Some speculations have been indulged in as to the difference between the several forms of preservatives due to the difference of solubility.

H. L.

Phosphotungstic Acids and Phosphomolybdic Acids.—HSIEN WU of the Harvard Medical School has made an elaborate study of these two groups of complex organic acids (*Jour. Biol. Chem.*, 1920, xliii, 189–220). For each of these complex acids, two series exist; the ratio of the phosphoric anhydride to the molybdenum trioxide (or tungsten trioxide) is 1 : 18 in the one series, and 1 : 24 in the other series. The uric acid reagent and the phenol reagent, which are used in the colorimetric determination of these respective compounds, contain complex acids in which the ratio is 1 : 18. Two phosphotungstic acids belonging to the 1 : 18 series have been prepared, and probably are isomers. The phosphomolybdic and phosphotungstic acids may also be used in inorganic analysis, for the detection of copper, the detection and colorimetric determination of phosphoric acid, as an internal indicator in oxidation and reduction reactions, and for similar determinations.

J. S. H.

NOTES FROM THE U. S. BUREAU OF MINES.*

MANUFACTURE OF SULPHURIC ACID IN THE UNITED STATES.

By A. E. Wells and D. E. Fogg.

SULPHURIC acid is one of the most important of all chemicals, not only because of the large quantities manufactured, but also because of the wide use of the acid in many different industrial works. The more important uses are as follows:

Dilute acid—that is 60°B. (78 per cent. H_2SO_4) acid, or weaker, is used in the manufacture of superphosphates, ammonium sulphate, and sulphates of metals; in precipitating barium and calcium sulphate for chemical purposes; in the manufacture of mineral acids; in pickling sheet iron for tinning and galvanizing; in various metallurgical operations; in the production of copper, zinc, nickel, silver, and gold; in the manufacture of galvanic batteries, storage batteries, electroplating, ether, organic coloring matters, starch, sirup, and sugar; and in innumerable other chemical and industrial operations.

Concentrated acid—that is, 78 per cent. to 100 per cent. H_2SO_4—is used for purifying benzene, petroleum, paraffin oil, and other mineral oils; for manufacture of nitroglycerin, pyroxylin, nitrobenzene, picric acid, and various other nitric compounds and nitro ethers; and in the manufacture of fatty acids by distillation.

Fuming acid (oleum) is used principally for the manufacture of explosives, such as nitrocellulose, trinitrotoluol, picric acid, and nitroglycerin; manufacture of certain organo sulphuric acids; and for fortifying weaker acids.

When the United States entered the war, heavy requirements for explosives manufacture made necessary a definite knowledge of the sulphuric acid capacity of the country. The Bureau of Mines, under the authority conferred by the explosives act, made a complete survey of the sulphuric acid situation. Data were collected on the situation and capacities of the various acid plants,

* Communicated by the Director.

sources of supply of raw materials, the principal points in regard to manufacturing processes, and the uses of the acid.

Bulletin 184 of the Bureau of Mines, entitled "The Manufacture of Sulphuric Acid in the United States," by A. E. Wells and D. E. Fogg, is a comprehensive report on the results of the investigation.

DETERMINATION OF WATER IN PETROLEUM EMULSIONS.

By E. W. Dean and W. A. Jacobs.

THE BUREAU OF MINES has recently developed an improved method of determining water in petroleum emulsions, the improvement consisting chiefly in the use of apparatus more convenient than any hitherto employed. The method has been used in the bureau's laboratories, as well as in a number of commercial laboratories with marked success, not only for determining the water content in heavy fuel oils, but also in tars, and in mixtures of powdered coal, oil, and water. A description has been published in the *Journal of Industrial and Engineering Chemistry* (Vol. 12, May, 1920, p. 486).

As the bureau has received various requests regarding sources of the apparatus used, it has taken steps to render the method available for general use.

Arrangements have been made so that the glassware and particularly the "distilling tube receivers" employed in the new method can be readily purchased from any one of several chemical supply houses.

The special electric heater designed and used by the bureau cannot be obtained in the market. Directions for making this heater have been published (*Journal Ind. and Eng. Chem.*, Vol. 10, Oct., 1918, p. 823), but many laboratories are not in position to construct such a heater, and many laboratories that are otherwise in position to do so, cannot purchase nickel-chromium wire, due to patent restrictions. Recent experiments by the writers have shown that an ordinary electric hot plate converted into a sand bath makes a usable substitute for the special heater. Also, it has been determined that either of two alloy compositions available for general purchase is a usable substitute for the nickel-chromium composition formerly employed in the heater. Fuller details are given in a recent report issued by the bureau.

EXPERIMENTAL SEPARATION OF LIME IN DOLOMITE.

By R. T. Stull.

In the dead burning of dolomite, for the preparation of fire resistant brick or other use the lime content is a hindrance to dead burning. The Bureau of Mines, at its ceramic experiment station at Columbus, Ohio, in the course of its investigations of the properties and preparation of dolomite, is making a study of comparative methods of separating out the lime. Experiments were made with the following three methods: (1) Dolomite was calcined and immersed for one day in running water. On account of the greater solubility of CaO in water as compared with MgO, the CaO content was reduced from 58 per cent. to 35 per cent., and the MgO content was increased from 42 per cent. to 65 per cent., the recovery of lime being 50 to 60 per cent. of the total content. (2) Calcined dolomite was boiled in water, and the resulting $Mg(HO)_2$ was then separated by flotation. The concentrate contained 65 to 75 per cent. MgO; the lime recovery was about 25 per cent. (3) There was added to calcined dolomite sufficient H_2SO_4 to convert all the CaO to $CaSO_4$. The $Mg(OH)_2$ was then separated by screening. The residue contained 75 per cent. MgO; the recovery was about 50 per cent.

The Industrial Reorganization of France. (*Le Génie Civil*, July 31, 1920.)—The Ministry of Commerce has published the results of its examination of the industrial situation of France before, during and after the war. A third volume contains the program for economic and industrial expansion in France. "All its future and, it may be added, its very existence depends upon it." Before turning to the program the French reviewer remarks: "In order that the purely industrial and commercial effort may not remain sterile, it must be supplemented by a social effort directed toward the improvement of the health of the people of France and against the diminution of the birth-rate, against alcoholism, syphilis and tuberculosis."

The great industrial impetus due to the war leads to the emphasizing of four points in the alliance of Science with Industry:

1. The directing authority should be in the hands of men of high technical attainments and even of high scientific training.
2. The employment of laboratories must be extended. Though the number of industrial laboratories is growing and though there are official laboratories of great value, still it must be

admitted that France has lagged behind Germany, Great Britain, and the United States in the establishment of these essential aids to manufacturing.

3. Better means must be devised for the prompt dissemination of technical and industrial advances. It is proposed to establish in Paris the "Office central de la Documentation."
4. Scientific Management of Factories should be the rule. The methods of Taylor are placed in the forefront.

M. Fleurent makes the interesting proposal that a State Council of Industry be instituted on which there shall be representatives of science, technology, industry, commerce, foreign trade, of workmen's organizations, of the law and of some governmental departments.

The relation of education to industry receives much attention. While the primary education of France merits nothing but praise, it is held that reforms are needed in the upper schools. The age of admission to such schools should be lowered so that young engineers might get to work at an earlier age. It is suggested that representatives of industry should sit on the highest educational council. Admirable provisions are suggested for the training of apprentices, of engineers, of business men and of farmers.

In the matter of the payment of workmen the giving of bonuses is recommended. "To the unskilled or unconscientious workman this method secures a minimum of wages depending on the time he spends at his work. The able worker can claim a considerable addition to his wages, if he is willing to avail himself of means of increasing his production."

This report, made by men of acute and analytical minds under the constraint of an imperative national necessity, is worthy of careful consideration by the industrial leaders of other countries.

G. F. S.

Bone black and decolorizing carbons are discussed by W. D. HORNE (*Jour. Ind. and Eng. Chem.*, 1920, xii, 1015–1017). The action of bone black is in part chemical, in part physical. The absorption of colors is essentially a mechanical or physical phenomenon. Bone black is used in filters 20 feet deep; 100 pounds of bone black will remove from a solution of 100 pounds of raw sugar about 25 to 35 per cent. of the ash, about 35 to 45 per cent. of the organic impurities, and about 75 per cent. of the color. With the rapid increase in the price of bone black, attempts have been made to find a substitute. Mineral matters, like fuller's earth or fragments of brick, have been impregnated with gelatin or molasses, then burned in kilns. Or vegetable matter, such as sawdust, has been impregnated with inorganic substances, then intensely heated, usually in the presence of steam.

J. S. H.

THE FRANKLIN INSTITUTE.

(Proceedings of the Stated Meeting held Thursday, October 20, 1920.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 20, 1920.

PRESIDENT DR. WALTON CLARK *in the Chair.*

Additions to membership since last report, 15.

Reports of progress were presented by the Committee on Library, and the Committee on Science and the Arts.

Mr. Coleman Sellers, Jr., Vice-President of the Institute, was recognized. He gave a brief account of the life and work of Dr. Joseph Priestley and presented to the Institute for its collections an air pump once the property of Doctor Priestley.* On motion of Dr. A. S. Cushman, duly seconded, the thanks of the Institute were extended to Mr. Coleman Sellers, Jr., and Mr. Horace Wells Sellers, the donors.

Doctor Hoadley was then recognized, and presented Mr. Edward Payson Bullard, Jr., of Bridgeport, Conn., to whom had recently been awarded the Howard N. Potts Medal for his Mult-Au-Matic machine. Doctor Hoadley said:

"*Mr. President:*

"One of the important functions of The Franklin Institute is that of granting recognition to inventors who have succeeded in putting into practical operation an invention that is of service to man.

"The investigations, required to determine who among the legions of inventors are worthy of such recognition, are put by the Institute, into the hands of the Committee on Science and the Arts.

"This Committee is composed of sixty members, each of whom is of wide experience and has expert knowledge in some scientific or technical field.

"Whenever an invention, that promises to be of sufficient merit, comes to the attention of the Committee, it is referred to a Sub-Committee on New Subjects and Preliminary Examination for consideration and if it meets with the approval of this Sub-Committee it is recommended to the General Committee for investigation. On being accepted, a Sub-Committee of investigation is appointed, consisting of members who are especially qualified to make an investigation in the field covered by the invention.

"This takes into account the originality of the invention, the soundness of the scientific and mechanical principles upon which it is founded and its success when put into practical application.

"Recognizing the value of the work done by the Committee on Science and the Arts, former members of the Institute have placed at its disposal certain funds from the income of which medals can be provided for inventions of especial merit.

* Mr. Sellers' remarks will appear in the next number of the JOURNAL.

"A little less than a year ago an invention of Mr. Edward Payson Bullard, Jr., was brought to the attention of the members. This is a mechanical device, the purpose of which is to increase the rate of production in the manufacture of parts of machines that are made in quantity.

"The fundamental idea of this invention is that of a multiple lathe, the operating parts of which are placed at equal intervals around a central vertical axis. The metal blanks from which the finished parts are to be made are firmly clamped upon pedestals that surround the central axis. These pedestals are rotated at speeds that are predetermined as required. Placed vertically above each pedestal is a tool carrier that clamps the required cutting tools.

"At the first station of this machine the finished work is removed and the new blank is inserted. When this is done the pedestals revolve bringing the blank to station 2, where a certain part of the work is done. The next movement of the pedestals brings the work to station 3, where further work is done. In this way the blank is brought successively under the different tools, and on reaching the last station it has become a finished product. To invent such a machine and to bring it to its present state of perfection in which it automatically turns out duplicate parts at a high rate of production has required years of intensive application in design, in testing and in modification, and to secure the correlation of all the operations required has called for a high degree of mechanical skill and ingenuity.

"The Sub-Committee of investigation closes its report with these words: 'For the originality and completeness with which this machine has been developed, for its adaptability to a large class of work, and for its economic value on account of its productiveness per man, per hour, per square foot of floor space, we recommend the award of the HOWARD N. POTTS GOLD MEDAL to Edward Payson Bullard, Jr., of Bridgeport, Connecticut, for his Mult-Au-Matic Machine Tool.'

"I have the honor to present Mr Bullard, the inventor of the Mult-Au-Matic."

The President presented the Medal and Certificate to Mr Bullard, who thanked the Institute for the honor conferred upon him.

Joseph S. Ames, Ph.D., LL.D., Director of the Physical Laboratory, The Johns Hopkins University, Baltimore, Md., then presented the paper of the evening, entitled "Einstein's Principle of Relativity and Its Bearing Upon Physics." It was shown that Einstein has introduced into the interpretation of the phenomena of nature, as observed on the earth, an entirely new concept and an entirely new method of approach. An account was given of his method and attention was called to some of the conclusions obtained by it and to their verification by experiment and observation. Especial emphasis was laid on the fact that Einstein has developed a method and not a theory. After a discussion of the subject the thanks of the meeting were conveyed to the speaker.

Adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting, held Wednesday, October 6, 1920.)

HALL OF THE INSTITUTE,
PHILADELPHIA, October 6, 1920.

MR. CHARLES PENROSE *in the Chair.*

The following reports were presented for final action:

No. 2751: Radojet Air Pump. The Edward Longstreth Medal of Merit to Messrs. Gottdank L. Kothny and Robert Suczek, both of Philadelphia.

No. 2754: The Work of W. L. R. Emmet. The Elliott Cresson Medal to Dr. W. L. R. Emmet, of Schenectady, New York.

The following report was presented for first reading:

No. 2753: Hite's Process of Sterilization by Pressure.

R. B. OWENS,
Secretary.

SECTIONS.

Electrical Section.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, October 14, 1920. Mr. Charles E. Bonine in the Chair.

Major J. O. Mauborgne, of the Signal Corps, U. S. Army, presented a communication on "Resonance Wave Coils for Radio Transmission and Reception." Consideration was given to the use of the resonance wave coil as a complete antenna system, including the antenna proper, the tuning elements associated with it and the ground or counterpoise. Various forms of resonance wave coils for reception were shown, as well as the action of the electromagnetic waves of the incoming signals on the wave coil. The question of the position of potential loops for various wave lengths was discussed. The various forms of detector circuits used and method of coupling same to wave coil were described. The directive properties of the resonance wave coil were pointed out. Some consideration was also given to duplex and multiplex reception, as well as the use of the device as a wave-meter. The subject was illustrated by lantern slides and numerous practical demonstrations given with the assistance of Captain Guy Hill, co-inventor of this system, and Major L. M. Evans, of the Signal Corps. Discussing the paper, Dr. Louis Cohen, of Washington, D. C., outlined some further probable early developments in the use of resonance wave coils. On motion, duly seconded, a vote of thanks was tendered to the speaker and his associates for the paper and demonstrations.

Adjourned.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, October 13, 1920.)

RESIDENT.

MR. MERRITT H. ADAMS, Vim Motor Company, 23rd and Market Streets, Philadelphia, Pennsylvania.

MR. EVAN MORGAN CLYMER, 142 East Fishers Avenue, Olney, Philadelphia, Pennsylvania.

MR. ROBERT LEE JICKLING, National Aniline and Chemical Company, Marcus Hook, Pennsylvania.

MR. ALGER L. WARD, Seventh Floor, 319 Arch Street, Philadelphia, Pennsylvania.

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MR. HUNTER C. PHELAN, 651 Salem Avenue, Dayton, Ohio.

MR. FREDERICK N. WILLIAMS, Massachusetts Oil Refining Company, East Braintree, Massachusetts.

ASSOCIATE.

MR. ELMER SMALLING, JR., 2939 North Camac Street, Philadelphia, Pennsylvania.

MR. FRANK L. WRIGHT, Atlas Ball Company, 4th and Glenwood Avenue, Philadelphia, Pennsylvania.

CHANGES OF ADDRESS.

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LIEUTENANT JOHN C. CORNELIUS, JR., 420 West Price Street, Germantown, Philadelphia, Pennsylvania.

MR. CHARLES HENRY DAVIS, Bass River, Cape Cod, Massachusetts.

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MR. CLARENCE P. FOWLER, 107 Elmwood Avenue, Narberth, Pennsylvania.

MR. LOUIS A. FERGUSON, 72 West Adams Street, Chicago, Illinois, Box 767.

MR. R. E. GILLMOR, 72 Westmont Boulevard, Montreal, Canada.

MR. JACOB HASSLACHER, Suite 2, 70 Westland Avenue, Boston, Massachusetts.

MR. RUDOLPH HERING, Spencer Arms, 140 West 69th Street, New York City, New York.

DR. DAVID W. HORN, 616 Montgomery Avenue, Bryn Mawr, Pennsylvania.

MR. LIONEL F. LEVY, 220 West Roberts Avenue, Philadelphia, Pennsylvania.

MR. MAX LEVY, Lenox Apartments, 13th and Spruce Streets, Philadelphia, Pennsylvania.

CAPTAIN CHESTER LICHTENBERG, 136 Waverly Place, Schenectady, New York.

MR. F. MACMURPHY, 542 West 112th Street, New York City, New York.

MAJOR C. W. MCMEEKIN, 2218 Roosevelt Avenue, Berkeley, California.

MR. B. B. MILNER, 141 East 44th Street, New York City, New York.

MR. RALPH H. MULLER, 1209 Rush Street, Philadelphia, Pennsylvania.

MR. H. H. PLATT, Scarsdale, New York.
PROF. I. M. RAPP, State University, Missoula, Montana.
MR. EDWARD RITTENHOUSE, Glen Loch, Chester County, Pennsylvania.
MR. CHAS. E. RILLIET, 4100-06 South Vermont Avenue, Los Angeles, California.
MR. JOSEPH B. ROHRMAN, care of H. E. Grau, Glenolden, Pennsylvania.
MR. WILLIAM SARTAIN, 140 West 57th Street, New York City, New York.
MR. LEWIS K. SILCOX, 7249 Cloes Avenue, Chicago, Illinois.
MR. H. B. SPENCER, President Fruit Growers Express Company, Munsey Building, Washington, District of Columbia.
MR. ERNEST STUTZ, 1705 Hope Street, S. Pasadena, California.
MR. EDW. H. TAIT, 401 Brighter Apartments, 2nd and Penn Streets, Reading, Pennsylvania.
MR. J. R. WATKINS, care of J. W. Darling Lumber Company, Cincinnati, Ohio.
MR. EARL H. WELTZ, Box 597, Penn's Grove, New Jersey.
MR. J. D. WILLIAMSON, JR., Latham Park, Oak Lane Post Office, Philadelphia, Pennsylvania.
MR. J. CLIFFORD WILSON, Room 205, 1509 Arch Street, Philadelphia, Pennsylvania.
MR. HOWARD SELLERS WORRELL, 100 East Montgomery Avenue, Ardmore, Pennsylvania.

NECROLOGY.

Mr. Henry J. Hartley, 1624 Oxford Street, Philadelphia, Pennsylvania.

Mr. R. L. O'Donnel, Pennsylvania Railroad Company, Pittsburgh, Pennsylvania.

Mr. Simon I. Kohn, 720 Market Street, Philadelphia, Pennsylvania.

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BOOK NOTICES.

METEOROLOGY. By R. G. K. Lempfert, M.A., C.B.E., Assistant Director of the Meteorological Office. 12mo, 183 pages, contents, 48 illustrations and diagrams and index. London, Methuen & Co., Ltd. 7s. 6d. net.

The problem of the weather has been studied from the earliest times, but it is practically within the memory of persons now living that it has been dealt with in a scientific manner. This phase began as with most sciences, by isolated observations by volunteer workers, but by degrees the greater nations perceived the value of such data, and hence today we have in these nations well-organized weather departments, that are not only collectors of data and students of atmospheric phenomena, but actively in the prophetic fields, publishing daily, or even more frequently, forecasts of the weather.

The book in hand is by an official of the British weather office, and presents in a compact form the leading features of observation and forecast as carried out in Great Britain. In normal times, the nations of western Europe interchange observations, and are thereby able to give more satisfactory information to their respective inhabitants. The many diagrams with which the book is provided serve to make clear the methods generally pursued, the main work of the central office being to interpret the data of the map. A very interesting map is that of the condition around the British Isles on February 17, 1915. This shows the "cyclone," "depression" or "low" condition, in which the lowest pressure is indicated southwest of Ireland, the "high" being in East France. These conditions showed that if a shifting of the low occurred toward the northeast, heavy weather would develop soon in the neighborhood of Denmark. German observers being prevented from getting the information to the west, and having an "anticyclonic" condition in their own area, assumed that it would be safe to make an air raid, and, accordingly, sent out two ships, which were shortly afterwards wrecked on the Danish coast.

The methods of making observations with the several standard instruments employed by meteorologists are described at some length, a chapter is devoted to the origin of changes in pressure, another to the tropical revolving storms and tornadoes, and the final chapter to the composition of the atmosphere. In the last chapter a paper by Humphreys is quoted in which figures are given showing that at high levels free hydrogen con-

stitutes a large part of the atmosphere. Chapman and Milne, however, have recently challenged this view and take the ground that helium is the predominating ingredient at the high levels, such as 150 kilometres.

Those who desire to know about the present development of the important science of the weather will find the book very useful.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 84, Data on the Design of Plywood for Aircraft. Preprint from Sixth Annual Report. 15 pages, illustrations, plates, quarto. Washington, Government Printing Office, 1920. In this report are given the results of investigations made by the Forest Products Laboratory of the U. S. Forest Service at Madison, Wisconsin, for the War and Navy Departments. Sufficient discussion on the mechanical and physical properties of plywood is included so that the data may be intelligently used. The data, although primarily intended for aircraft design, have a broader field of application.

Report No. 92, Analysis of Wing Truss Stresses. 20 pages, illustrations, quarto. Washington, Government Printing Office, 1920. This report is concerned with the analysis of the effect of redundancies, and particularly of the external drag and stagger wires. The stresses in a typical training machine have been worked out for several conditions of flight, the method of least work having been applied, as an illustrative case. The chief conclusions reached are that the use of more than one external drag wire on each side is wasteful and undesirable, that the effect of the stagger wires in speed diving is important and serves to reduce greatly the load in the lift trusses, and that the advantages in reduction and uniformity of stresses to be gained from the tensiometer in practical rigging are great enough to justify the general introduction of that instrument. In particular, the stress wires are usually set up much too tightly.

Melted Basalt. (*La Nature*, October 2, 1920.)—This volcanic rock is hard to shape with chisel and hammer. Doctor Ribbe in Auvergne has, however, found that it may be melted and molded with no great difficulty by working at about 1300° C. In his preliminary experiments he obtained a glassy substance, but, fortunately, he has been able to apply a devitrifying process, which restores the crystalline structure of the original rock. The melted rock is superior to the natural basalt in resistance to wear and scratching. It is in consequence valuable for paving, for curbstones and for stairs. This property added to the exactitude of form and dimension achieved in the process of molding points to extended usefulness in building.

Acids do not attack the melted basalt, it is claimed, and it can be used for vats, etc., in the manufacture of chemical products. It is an excellent electrical insulator and metallic posts and fittings are fixed in a very satisfactory way by inserting them in the basalt while it is still pasty.

G. F. S.

CURRENT TOPICS.

Motor Fuels.—The problem of increasing the supply of volatile fuels for internal combustion engines still presses heavily upon the world, giving rise to active exploration of areas and to investigations into the artificial production of such materials. It seems probable that the competition between several of the great nations for the control of existing or possible oil fields will be one of the most disturbing influences on the peace of the world. Already British authorities are claiming a large share in the control of such supplies. However, attention is being strongly directed to artificial fuels, among which alcohol is prominent. Alcohol has several advantages as a motor fuel; it is without offensive odor, is perfectly combustible under simple conditions, and the fire-risk is much less than that of the common petroleum and tar products. In a sense, the supply is inexhaustible, and production not subject to monopoly by any one of the great nations for it is obtainable from any vegetable containing starch or sugar, and by means of special methods even from cellulose.

The British Fuel Research Board has just issued a pamphlet in which the serious problems of supply of motor fuel for British uses is discussed at some length. It appears that in 1919 the world's production of crude petroleum was nearly 20 billions of U. S. gallons of which the United States contributed about 74 per cent. The consumption, however, exceeded the production. The lighter portions of petroleum are used for air and road transport. As England imports almost all of this class of fuel, it is obviously a very important matter for that country to obtain control of a large supply. Benzene (from coal-tar) is suitable, and as this is easily obtained from coal, attention has been directed to improving the yield. Inasmuch as coals yielding large amounts of volatile hydrocarbons are abundant in many parts of the world, the development of this source of motor fuel is well worth the attention of research chemists.

The report states that so far as alcohol production is concerned, the area included in the United Kingdom, that is, British Isles, cannot be made to yield sufficient starch- or sugar-bearing plants to solve that phase of the problem. Of course, the British Empire is a different matter, especially in view of the enormous areas that have been acquired by the settlement of war, but production in distant colonies involves protection by a navy in war time, and in peace and war an expense of transportation. The alcohol question is complicated in all countries by the social relations of alcohol, and its use as basis of revenue by taxation, so

that even if it was the best of fuels its manufacture will be complicated by official supervision.

The conclusions that the British authorities give in the report under consideration are as follows:

Coal is the largest as well as the cheapest source of fuels for transport purposes.

Means are already at hand for "sorting out" the potential energies of coal into forms of different availability and value.

The more volatile products, such as benzene, are so relatively costly that they ought to be used only for air transport or the lighter and swifter forms of road transport.

Town gas and coke-oven gas are applicable, and it seems practicable to use these in city and suburban traffic if light and safe containers could be constructed and stations established at which the supply could be replenished.

By carbonization at about 600° C., gas of twice the usual calorific values of ordinary gas is obtainable and the coke is a tarless, smokeless fuel, easily lighted and free burning. The cost per thermal unit by these latter methods will be far less than the cost with gasoline at present prices.

H. L.

An Extension of the Balmer Series of Hydrogen and Spectroscopic Phenomena of Very Long Vacuum Tubes. R. W. WOOD. (*Proc. Royal Soc.*, No. A 687.)—The light from hydrogen in the sun shows a series of lines no less than thirty-two in number, which follow Balmer's law. The light from the same gas in a vacuum has hitherto been made to yield on the first twelve lines of the series. In the present investigation a tube about 2 m. long and 7 mm. in diameter was used. A length of 40 cm. was straight. From each end of this portion of the tube a stretch of 80 cm. was bent away sidewise and at the distant end an electrode was fixed. The light from the straight part of the tube was used for the observations and the tube was placed end-on with respect to the spectroscope, so that the entire 40 cm. might contribute light. When the discharge was traversing the tube the color was bluish-white for about 50 cm. from each electrode, "while the straight portion is of a fiery purple, of an intensity which is almost painful to the eyes." An alternating current was used.

Professor Wood succeeded in photographing the series of lines as far as the twentieth, whose intensity he estimates to be probably less than one-millionth that of the alpha line of hydrogen. He remarks that "the experiment led to the discovery of a most remarkable type of tube and a wholly new set of spectroscopic vacuum-tube phenomena. It is probable that a quite new field is opened up for the separation and study of compound spectra."

G. F. S.

The Blue Sky and the Optical Properties of the Air. LORD RAYLEIGH. (*Nature*, July 8, 1920.)—In a lecture on this subject delivered at the Royal Institution, May 8, 1920, the present Lord Rayleigh presents the explanation of the blue of the sky which we owe to his distinguished father. When light passes through the atmosphere, it is acted on by the molecules of the gases present. The longer waves pass through with little change, so that the transmitted light is rich in red and yellow. Thus the vivid colors of sunrise and of sunset are accounted for. The short waves, on the other hand, are scattered laterally and in this way blue light comes from the group of illuminated molecules. Soapy water or dilute milk is yellowish by direct light but appears bluish when viewed from the side.

A thick layer of ozone absorbs such wave-lengths of the light that traverse it that the emerging light is blue. This has led to the theory that this gas is responsible for the blue of the sky. No doubt it may contribute in a slight degree to the effect, but that it is not the predominating cause is shown by the redness of sunsets. At this time of day the length of the path of air traversed by the light is at a maximum and the absorption by ozone is likewise at its maximum, but the colors we see are by no means blue. Nor can absorption by ozone account for the polarization of light from the sky.

Ozone does, however, leave its hall-mark on the light which reaches the earth from the sun. The lecturer, to prove this, showed the following experiment, never before exhibited to an audience. By means of lenses and prism of quartz the spectrum of light from an iron arc was formed. The presence of the ultra-violet spectrum was demonstrated by placing a screen of barium platinocyanide beyond the violet end. The ultra-violet rays made this glow with green light. A glass tube six inches long was put in the path of the light before it was dispersed. When oxygen that has passed through an ozone generator flowed through the tube then that part of the spectrum due to the light coming through the tube was seen by the audience to lose most of its ultra-violet part. This again appeared when oxygen alone flowed through the tube. The gas from the ozone generator has less than 1 per cent. of this constituent in it, yet it cuts off the spectrum at about 2900 angstroms. The spectrum of sunlight shows the absence of the same wave-lengths. Detailed comparison of the spectrum of sunlight after it has passed through the atmosphere of the earth with the spectrum of the light of the iron arc after traversing a body of ozone shows that the absorption bands are the same in both cases and the conclusion is justified that the brevity of the ultra-violet spectrum of sunlight is due to absorption by ozone in the atmosphere.

There is scarcely any ozone near the surface of the earth. This was proved by the examination of light from a terrestrial

source after it had passed through four miles of air. There was no evidence of absorption due to ozone.

The tenuous ozone of the upper air, little known and inaccessible as it is, plays an important part in the life of man by abstracting from the sunlight the ultra-violet rays which the human eye could not endure.

In *Nature*, July 22nd, J. N. PRING speaks of a method he has devised for the determination of ozone and for discriminating it from oxides of nitrogen. He finds that at an altitude of 10,000 feet the atmosphere contains five millionths by volume of ozone. No increase in the content was discovered in passing from 4 km. to 20 km. At the Mosso Laboratory on Monte Rosa, altitude 15,000 feet, only one millionth of the volume of the air was ozone.

G. F. S.

Nitrate Content of Potable Water.—M. STARR NICHOLS of the University of Wisconsin (*Jour. Ind. and Eng. Chem.*, 1920, xii, 987–989) has determined the nitrate content of 808 samples of water which were found to be safe on bacteriological examination; 87 per cent. of the 446 samples from deep or drilled wells, 74 per cent. of the 250 samples from shallow or dug and driven wells, 77 per cent. of the 71 samples from springs, and all of the 28 samples from lakes, and 13 samples from rivers did not contain more than five parts of nitrate nitrogen per million. It is concluded that a potable water, which contains five or more parts of nitrate nitrogen per million, be considered a potentially dangerous supply until a sanitary survey has been made. This constituent should be determined in every examination of a ground water.

J. S. H.

Helium in Canada.—The studies of Dr. J. C. MCLENNAN of the University of Toronto (*Canadian Chem. Jour.*, 1920, iv, 253–254) show that the natural gas of Canada contains varying amounts of the rare gas helium, which is of great value as a substitute for hydrogen in aeronautics, especially in warfare. The gas from some fields has a helium content of 0.34 per cent. Helium of a purity of 87.90 per cent. has been extracted from the natural gas; and it is apparently possible to obtain in this way helium of 97 per cent. purity with an efficiency of 80 per cent., at an estimated cost of less than two and one-half pence per cubic foot. Canada is the only part of the British Empire that contains helium in any worth-while quantity.

J. S. H.

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